Comparing the Levels of Light Intensity of Different Colors of Flames Produced by Strontium Nitrate, Potassium Chloride, Sodium Chloride, Cuprous Chloride, and Ethanol-Based Hand Sanitizer

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Abstract

This experiment tested the effects of strontium nitrate, potassium chloride, sodium chloride, and cuprous chloride on the light intensity of an ethanol-based hand sanitizer flame to determine which would produce the most intense light. A flame containing sodium chloride produced the most intense light, with an average measurement of 67.05 lux in three trials. The second most intense light was produced by potassium chloride, with an average of 36.55 lux - However, this may have been an inaccurate result due to the contamination of sodium chloride in the trials. The third most intense light was produced by cuprous chloride, with an average intensity of 29.56 lux. Strontium produced the least intense light compared to the other three salts that were tested, producing an average of only 12.28 lux throughout the three trials. The strontium-produced flame was only slightly more intense than the nearly clear control flame produced by the ethanol-based hand sanitizer, which produced an average of 3.10 lux. This may have been due to the strontium in the flame having a shorter effective life span than the other salts.

Introduction

The intense heat that results from a flame's chemical reactions can be enough to cause some elements within those reactions to emit light. When a source of energy, such as heat, comes in contact with a substance, it can cause some electrons within the substance to become "excited" and raise to a higher energy state. Such energy states are unbalanced; electrons in high energy states are constantly moving. At some point, the electrons move back down to their ground state. When this happens, a photon that correlates with the specific difference in energy levels is emitted. Different differences in energy states result in emission of different wavelengths of visible light from the flame (Franklin).

Light is transported to the eyes by means of light waves. Waves carry energy, and the amplitude, or height, of a wave is generally a measure of how much energy the wave carries. The amount of energy a wave carries depends on both intensity and wavelength. Light intensity is the range at which light energy is delivered to a surface over time - "energy per unit time per area" (The Regents of…). Wavelength is simply the length of a wave, and it is measured in nanometers. The labeled structures of a wave can be seen in **Figure 1**. Individual waves of light are different in length; they have different wavelengths. Shorter wavelengths carry more energy than longer wavelengths; more energy generally means higher intensity (The Regents of…). Different wavelengths of light translate to the eyes as different colors. Wavelengths between 400 and 420 nanometers (nm) produce violet colors; 420-440 nm waves result in indigo; blue is created when wavelengths are between 440 and 490 nm; green is a result of 490-570 nm; light appears yellow when the wavelengths are between 570 and 585 nm; 585-620 nm-waves create orange light; finally, red light appears when wavelengths are between 620 and 780 nm ("Visible Spectrum").

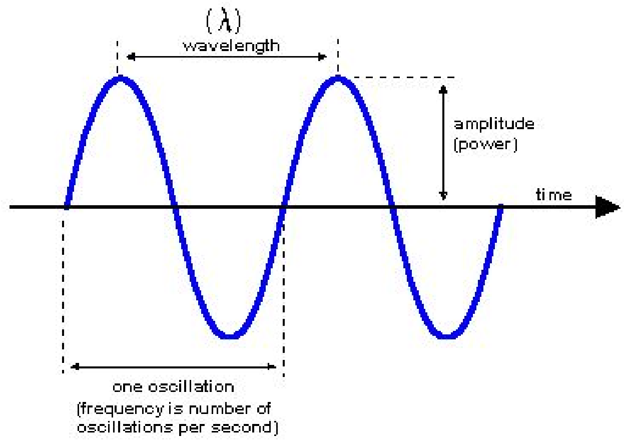


Figure 1. A labeled diagram showing the anatomy of a wave, including what a wavelength is and the fact that greater amplitude means a wave carries more energy ("Wavelength").

This experiment analyzed the effects of color on the light intensity of a flame. The initial question asked was, how do the light intensity levels of a standard ethanol alcohol-based hand sanitizer flame (clear in color) and flames with strontium nitrate (red), sodium chloride (yellow), cuprous chloride (green), and potassium chloride (purple) compare to one another? The predictions made based on this question were as follows. The potassium chloride (purple) flames would have the highest light intensity because purple colors have the shortest wavelengths of all the colors on the visible spectrum; as stated previously, shorter wavelengths are known to carry more energy and more energy generally means higher intensity. On the opposite end, the strontium nitrate flames would have the lowest light intensity because the red colors have longer wavelengths and therefore less energy. Finally, the intensity levels of the sodium chloride (yellow) flames and the cuprous chloride (green) flames would fall in between the intensities of the red and purple flames because yellow and green wavelength measurements fall in between those of red and purple colors.

The answer to the initial question and the results of this experiment could potentially prove to have great social importance. Road flares currently contain strontium nitrate as their primary source of color. If strontium nitrate proves to be the brightest of the flames tested, then this experiment will defend why strontium nitrate is a good compound to be used for this. However, if one of the other compounds proves to produce a brighter flame, then it could be determined that road flares should use a different compound other than strontium nitrate. This would be because if a brighter compound was used, less of the material would be needed to produce a bright flame. Additionally, this would help the road flares cost less to produce since less quantities of the compound would be required for each road flare.

This experiment required a Vernier Light Sensor. This probe comes pre-calibrated, which makes it quicker to use than some of Vernier's other probes. The probe utilizes a silicon photodiode, which generates a voltage proportional to light intensity. Additionally, "the spectral response approximates the response of the human eye" ("Light Sensor"). This probe also comes with some limitations. It can only measure wavelengths within the human eye's visual spectrum, or between 400 and 800 nanometers in length. The unit of measurement is lux; 1 lux = 1 lumen/meter^2. This reflects how light intensity is the rate at which energy is delivered to a surface over time. The higher the lux, the faster energy is being delivered and the brighter the light source is (The Regents of… and “What Is the…”). This probe has three different ranges of measurement. The smallest range - 0 to 600 lux - is the most sensitive and efficient, with an average standard deviation of 0.2 lux. The second range available is 0 to 6000 lux, which has an average standard deviation of 2 lux. Finally, the range with the greatest standard deviation of 50 lux is the 0 to 150,000 lux range. This experiment utilized the 0 to 600 lux range, as the light intensity of a small flame was unlikely to go above 600 lux. It is recommended that this probe be used in a dark room, as it is possible for it to pick up surrounding light (“Light Sensor User”).

Materials and Methods

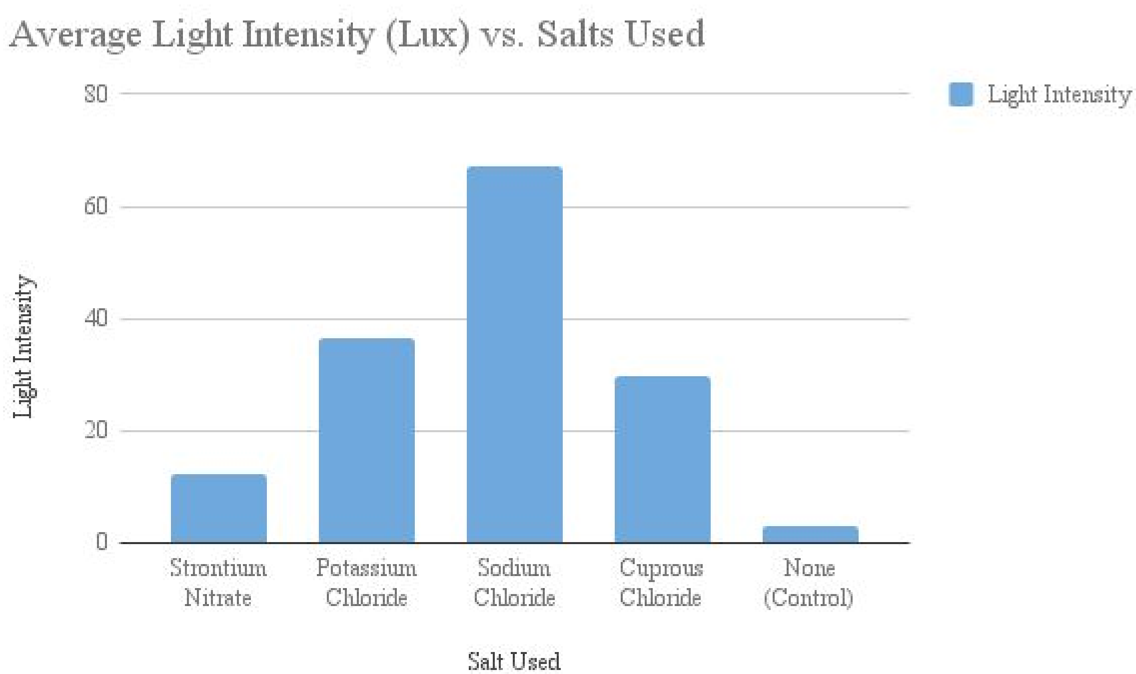
To act as fuel for the flames, hand sanitizer with an ethyl alcohol base of 70% concentration was chosen. This was for multiple reasons, primarily involving safety. Gel sanitizers burn at relatively cool temperatures compared to gas and wood, with sanitizer temperatures peaking between 500ºF and 1000ºF (as compared to wood, which generally burns at 1100ºF on average) (Cavage and Papiewski). In terms of the compounds chosen to burn to produce colors, highly volatile compounds (i.e. chlorides) produce the most intense colors. A compound is considered volatile when it can easily be converted into a vapor or a gas (Lerner). For this reason, strontium nitrate, sodium chloride, cuprous chloride, and potassium chloride were the chosen compounds to create vibrant colors within the ethyl alcohol-based hand sanitizer. Strontium chloride would have been the ideal compound to use since chlorides are more volatile, but this was not available at the time of the experiment. When burned, compounds containing strontium are known to have red flames; sodium chloride results in yellow flames; cuprous chloride flames are green; potassium chloride makes a flame purple (Maggio). A complete list of the materials used in this experiment was as follows: 1 Bic multi-purpose lighter, 3-5 glass petri dishes (can be washed in a sink between trials), 3 pairs of safety goggles, 1 vacuum hood, 1 relatively dark room for experimentation, 1 scoopula, 5.00 grams of strontium nitrate (for red flames), 5.00 grams of sodium chloride (for yellow flames), 5.00 grams of cuprous chloride (for green flames), 5.00 grams of potassium chloride (for purple flames), 1 scale that measures in grams to the hundredths place, 1 Vernier light probe, 1 computer equipped with Logger Pro software, 1 LabPro interface, 1 sink with water and 1 roll of standard paper towels to clean out petri dishes, and 1 Kroger 32-ounce bottle of hand sanitizer with a 70% ethyl alcohol content.

First, the petri dish was placed on the scale which was then zeroed out. 5.00 grams of a salt were added to the petri dish. The scale was then zeroed out again. 2.00 grams of hand sanitizer were added to the petri dish. The petri dish was placed under the vacuum hood. All the lights were then turned off in the testing environment, with the exception of the emergency light which could not be turned off. A Bic multi-purpose lighter was used to ignite the salts and the hand sanitizer. The light sensor probe was then held directly in front of the flame using the

Logger Pro software to record the data. After the data was collected, the flame burned out on its own and the petri dish was removed from the vacuum hood using a heat-resistant glove (the dish was hot). The dish cooled off and was cleaned with water and paper towels. This process was repeated 3 times with each salt. Control trials were completed with this same procedure, except only hand sanitizer was added to the petri dish and the compound powders were excluded from these trials.

Results

The light intensity varied over time for each trial, thus the average was used to better quantify the results. Standard deviation was calculated by the equation $D = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n}}$. D represents the standard deviation value, x represents each point of data, $\bar{x}$ represents the average of the data sets, and n represents the number of points in the data set.



Graph 1. The average light intensity (in lux) produced by a strontium nitrate, potassium chloride, sodium chloride, cuprous chloride, and plain ethanol flame.

Table 1. Light Intensity of Strontium Nitrate Flames

Trials	Average Light Intensity (lux)
Trial 1	26.97
Trial 2	7.58
Trial 3	2.30
Average	12.28 + 10.60

Table 2. Light Intensity of Potassium Chloride Flames

Trials	Average Light Intensity (lux)
Trial 1	18.81
Trial 2	37.76
Trial 3	53.08
Average	36.55 + 14.01

Table 3. Light Intensity of Sodium Chloride Flames

Trials	Average Light Intensity (lux)
Trial 1	79.17
Trial 2	63.47
Trial 3	58.52
Average	67.05 + 8.80

Table 4. Light Intensity of Cuprous Chloride Flames

Trials	Average Light Intensity (lux)
Trial 1	47.16
Trial 2	17.78
Trial 3	23.74
Average	29.56 + 12.68

Table 5. Light Intensity of Ethanol Flames

Trials	Average Light Intensity (lux)
Trial 1	1.21
Trial 2	2.42
Trial 3	5.66
Average	3.10 + 1.88

Discussion

Prior to the official conduction of the experiment, it was hypothesized that different wavelengths of light emitted from a fire would all have different levels of intensity. The potassium chloride (purple) flames were predicted to be the most intense and the strontium nitrate (red) flames to be the least intense, with sodium chloride (yellow) and cuprous chloride (green) falling in between. However, these hypotheses proved to be incorrect overall. The sodium chloride (yellow) flames proved to be the most intense, with an average of 67.05 ± 8.80 lux which was dramatically higher than the other flames tested. The only hypothesis made that was correct was that the strontium nitrate (red) flames would be the dimmest (with the exception of the control); the average light intensity of the strontium nitrate flames was 12.28 + 10.60 lux. Because strontium nitrate was not the brightest of the flames, this provides a solution to the social importance discussed in the introduction. Since sodium chloride proved to be considerably brighter than strontium nitrate, it could be recommended that sodium chloride should be used in road flares instead. This would be because since sodium chloride flames are so much brighter than strontium nitrate flames, less of the compound would need to be used to have an equally bright flare, or the same amount could be used to create an even brighter flare. Sodium chloride, also known as table salt, is a very common substance compared to strontium nitrate, so it is much cheaper and would reduce the cost of the production of road flares. If a chloride would not work as a road flare, then sodium nitrate could be used, as it is the sodium that produces the bright yellow color of the flame and the chloride helps make it even brighter (Maggio). Either way, sodium would create a brighter road flare than strontium currently does.

There were multiple errors that occurred in the process of conducting this experiment that likely affected these results. The potassium chloride (purple) flame proved to have the second-highest light intensity which contradicted the original hypothesis. However, there appeared to be streaks of yellow present in the potassium chloride flame, meaning that the petri dish was probably contaminated with sodium chloride; therefore, the results were skewed. In terms of the strontium nitrate flame, there was an issue with our initial experimental design from the start. The variables were not properly controlled, since strontium nitrate was not a chloride but all of the other colors of flames were produced by chlorides. Since chlorides are known to produce intense colors, the experiment was biased in favor of the other colors, as their compounds contained chlorine while strontium nitrate's did not. Strontium chloride was not available at the time of the experiment, but in future conductions of this experiment, strontium chloride should be used to increase the level of control between the variables. Additionally, the red color in the strontium nitrate flame flashed in quick streaks within the flame; the flame was primarily clear from the alcohol but some streaks of red flashed through it. This was true in all three trials. This may have affected the light intensity of the strontium nitrate flames in comparison to the other flames because the other flames had more consistent color flowing through them, while the red color unevenly flashed in various areas of the flame. This difference may have again been because the red flame was not made with a chloride like the other flames were, so the solution to this error in the future would be to use strontium chloride instead of strontium nitrate.

The main challenge that occurred in the conduction of this experiment was the fact that the probe struggled to pick up the flames. Even when the probe was held directly into the flames, the Logger Pro displayed the same data as it had for the plain hand sanitizer flame. The first measure taken to attempt to solve this problem was a black paper was taped to the window of the vacuum hood to block out as much outside light as possible. However, this was not an effective solution because the probe still showed the same readings, and the paper was dangerously close to the flames so this posed a safety hazard. The solution to this challenge proved to be in the compounds themselves. The original experimental design called for 2 grams of each powder because it would be ideal if as little powder could be used as possible because the powders were expensive. When this amount was increased to 5 grams, the flames were suddenly much brighter according to the probe and the readings. One challenge that stayed consistent between all the trials was that the flames were constantly flickering, as flames do, so with the level of intensity constantly changing between the different areas of the flame, it was difficult to get a consistent reading. There isn't really a way to fix this in future conductions of this experiment, as flickering within flames is a natural property of flames. Overall, the main solutions to overcoming the sources of error and challenges this experiment posed are to use strontium chloride instead of strontium nitrate, and to use more of each compound to create higher results as a whole.

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