Investigating the Correlation Between the Polarity of Alcohols and the Fluorescence Properties of Turmeric

IB HIGHER LEVEL CHEMISTRY INTERNAL ASSESSMENT

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Introduction:

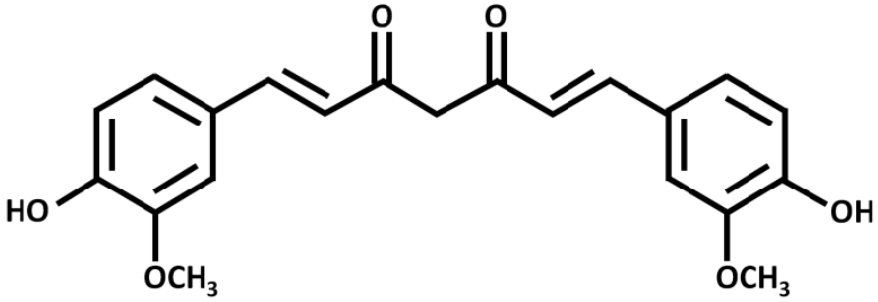
The research question in investigation is:

To what extent does the change in polarity of various alcohols (methanol, ethanol, 1-pentanol, octanol and dodecanol) alter the fluorescence intensity of turmeric under ultraviolet (UV) lighting, investigated using a spectrophotometer?

Curcuma longa, known as turmeric (chemical formula: $C_{21}H_{20}O_6$), is a natural South Asian plant and spice notorious for its rich yellow colour (Brown, 2022). It is used in my cultural Indian cooking, as well as for many herbal or 'ayurvedic' purposes, and during weddings or religious ceremonies. My idea for investigating the properties of turmeric stemmed from my love for cooking, where the colour of my rice would instantly turn bright yellow upon adding mere increments of the spice but not with vegetables; I wanted to know how chemistry behind turmeric brightening foods. Upon asking my teacher, she suggested that, besides equilibrium, salt may influence the intensity of turmeric in starch, relating it to polarity and salting out. Although it is true, I discovered that polarity also allows turmeric to glow in ultraviolet (UV) light when dissolved in alcohol, intriguing my inner child to experiment with fluorescence, and correlating it to colour intensity due to polarity.

"Polarity is the electric condition that determines the direction of current flow relative to the electrode." (Team, 2023). Turmeric, specifically curcumin, the chemical that gives turmeric its enriched pigment, is a polar molecule due to its two phenol groups on both sides of the molecule and the double bond oxygens (seen in *Image 1*), allowing for strong intermolecular forces (IMFs) like hydrogen bonding within the hydroxyl groups, a dipole-dipole moment of 10.77D at the ground state and London Dispersion Forces (LDFs) to be present (Hewlings et al, 2017).

Image 1: Chemical Structure of Curcuma Longs (Turmeric)



Source: (Büsselberg et al., 2020)

From the rule "Like dissolves like," any polar substances, water and starch especially, would dissolve turmeric. Surprisingly, **cellulose,** present in curcumin, has a stable crystalline state and non-polar methyl groups and aromatic rings (Zheng et al., 2020). Consequently, its free energy of dissolution (ΔG_d), the Gibbs free energy change as matter dissolves into a solvent (*Chemistry,* n.d), becomes non-spontaneous ($\Delta G_d > 0$), making turmeric **hydrophobic**. However, it is soluble in alcohols, especially ethanol, because they break turmeric's polymer chains, allowing it to dissolve.

The electron starts in the ground state, and as UV light shines over it, the electron gets 'excited' and moves to higher energy, absorbing UV radiation along the way (UV-induced fluorescence)

(Measday et al., 2017). At maximum potential energy, it returns to the ground state, emitting energy as light in the visible spectrum. A preliminary experiment questioned whether electrons emit light in water and starch instead of ethanol. The observations concluded no fluorescence because of turmeric's insolubility in water. Additionally, it was qualitatively noted that the water-turmeric solution was darker in colour than the alcohol (seen in *Image 2*). Similarly, as alcohols get larger in size, they become more non-polar as their hydrocarbon group is bigger than the OH group (n.d).

Image 2: The difference in colour intensity (qualitatively and with visible light) of turmeric in water VS. ethanol VS. methanol.

From this knowledge, a **null hypothesis** is: **The increased polarity should increase the energy gap, and thus the fluorescence intensity (while decreasing the wavelength) of turmeric.**

Methodology:

Variables:

The **independent** variable is the type of alcohol used, and its relative polarity and physical properties. Here, **methanol** (1 carbon chain)**, ethanol** (2 carbons)**, 1-pentanol** (5 carbons)**, octanol** (8 carbons) and **dodecanol,** known as dodecyl alcohol (12 carbons) were chosen. As mentioned previously, turmeric is most soluble in ethanol, suggesting it is more polar. The only alcohol available in this experiment with a higher polarity than ethanol is methanol, resulting in them being the top choice. The other chosen alcohols have approximately incremental carbon chain increases (they increase by 3 carbon chains each time). Decanol or un-decan-1-ol were unavailable, so solid dodecanol was used. To analyze their properties, the following databases were consulted:

- **PubChem**
- **CRC Handbook of Chemistry and Physics**
- **Stenutz.eu**

PubChem is primarily chosen as it compiles a detailed list of properties from various peer-reviewed sources, and is from the National Center of Biotechnology Information, managed by the United States National Institutes of Health, ensuring it is accurate and non-biased. The CRC Handbook of Chemistry and Physics and Stenutz.eu were used to fact-check any research and ensure the numbers matched or for information unavailable in PubChem.

The **dependent** variable is the fluorescence intensity and wavelength. Fluorescence, a form of luminescence (emission of light from non-heated substances), is the ability of chemicals to emit

visible light after absorbing radiation not apparent in the visible region (Schwarcz, 2017). This is determined empirically with a spectrophotometer, which determines the intensity of light absorbed as a wavelength. A spectrophotometer is deemed the best form of available technology because it offers varying functions where light intensity and fluorescence can be examined from multiple lights, as opposed to a colourimeter which measures the transmission of rays absorbed by a solution and has limited colour ranges. Although this spectrophotometer had blue light instead of UV light, it is valid since blue light ways have wavelengths of 400-500nm, which border the wavelengths of UV light. Furthermore, it was reflected that although blue light may not provide the same result as with UV light, a plastic cuvette absorbs UV light, meaning that the wavelength would have been larger, unless quartz cuvettes were used, balancing out the effects. However, as a cross-checking method to ensure the wavelengths are similar, a pixelation method was used; the app *Light Spectrometer* on Android analyzed the wavelength at which fluorescence occurs in UV light.

The controlled variables are listed in *Table 1* below:

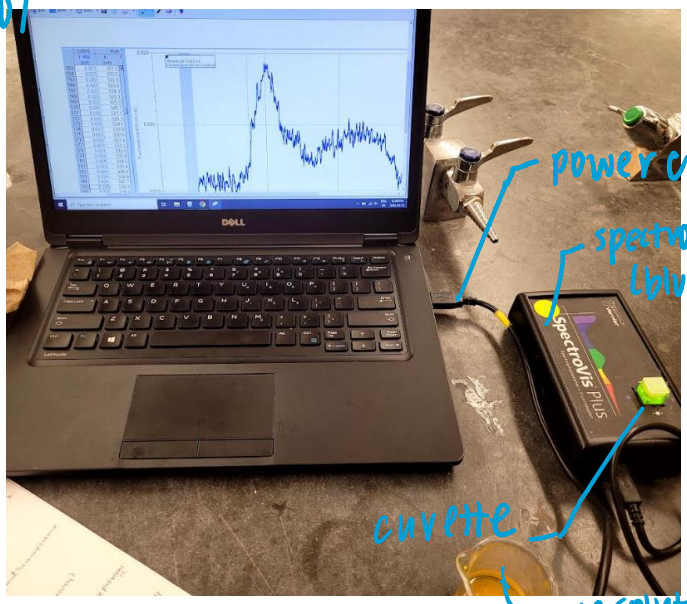
Table 1: Controlled Variables in this Investigation

Controlled Variable	Reasoning and how it is Controlled
Amount of Turmeric and Alcohol Mixed in a Solution	The chemical reaction between alcohol and turmeric is: $C_{21}H_{20}O_6 + C_2H_6O \rightleftharpoons C_{23}H_{26}O_7$ From Le Chatelier's Principle, if there is less alcohol, then the equilibrium shifts to the left, favouring reactants, and the colour may intensify or if there is excess turmeric in one reaction than another reaction involving another alcohol, then the turmeric residue from the bottom can become apparent. • 0.150g of turmeric and 20 mL of each alcohol were mixed each time. 0.150g is deemed sufficient upon testing the colour and approximating what would be an ideal amount
Amount of UV light shined	When taking pictures for pixelation, too much UV light can change the distance the waves have to travel and can lead to exposure. • The UV light was held approximately 5 cm away from the solution, measured using a ruler afterwards and there were landmarks in the surroundings, like a benchmark serving as an indicator as to where the torch needs to be held. Tape markings can also be used. • The same UV light source was used through the experiment.
Temperature	From chemical kinetics, rate of reaction increases with temperature, as more particles reach minimum activation energy (E_A), and the colour intensifies. • The experiment was done at room temperature (approx. 25°C) and solid dodecanol heated to liquid is slightly cooled before adding turmeric.
Darkness and Room Conditions	This can interfere with the lighting when taking pictures and observations. • Lights were off during pictures and often done in the bottom of a table counter where outside light was minimized.
Structure of alcohols	All chosen alcohols have a hydroxyl (OH) group on their first carbon, which may cause a difference in physical properties than alcohols which do not have a terminal OH group. This ensures that the carbon chain increase is the only cause for the polarity change.
The angle at which images were taken	To ensure the UV lighting is consistent and the images do not receive excess lighting/darkness, they were taken right above the solution and a water bottle was used to hold the phone upright, minimizing angle distractions.

Apparatus:

- 0.150g of turmeric for each run (5 trials total) ($\pm 0.001g$)
- 20 mL of methanol [$liquid\ (l)$]
- 20 mL of ethanol (l)
- 20 mL of 1-pentanol (l)
- 20 mL of octanol (l)
- 20 mL of dodecanol ($solid$)
- 5 40mL beakers ($\pm 5.0mL$)
- Glass rod(s)
- Plastic tray(s)
- Milligram balance ($\pm 0.001g$)
- Graduated Cylinder ($\pm 0.05mL$)
- Hot plate
- 5 plastic cuvettes
- A Vernier Spectro Vis Plus Spectrophotometer ($\pm 0.1nm$)
- Vernier *LoggerPro* Software
- A laptop with a USB C cord
- UV light source (here, a Suncatcher UV Sanitizing Wand Torch was used)
- Paper Towels
- Tape and Marker

Image 3: (left) Apparatus Setup of Spectrophotometer (right) Sample of how the turmeric solution look under UV light.



Procedure:

1. Place a plastic tray onto a milligram balance and press “zero”/ tare.
2. Using the zeroed milligram balance, measure out 0.150g of turmeric onto the tray.
3. Pour 20 mL of methanol into a graduated cylinder, reading the amount at the bottom of the meniscus.
4. Pour the methanol into a small 40mL beaker and label the beaker “methanol.”
5. Add the turmeric into the alcohol-filled beaker and lightly stir for 10-20 seconds with a glass rod.

NOTE: Find preliminary data using *Light Spectrometer.* To calibrate the app, place a white sheet of paper (wavelength 457nm) (Collins et al., 2015), and aim the camera as close to the solution to avoid anything interfering and disturbing the accuracy. Ensure the UV light shines about 3 cm from the beaker so the light is hit throughout. Tape marking where the UV light is placed can help.

6. Open *Vernier LoggerPro* software on a laptop and connect the spectrophotometer to the laptop via a power cord. A green light indicates that the spectrometer is connected.
7. Go to the settings option and make sure that fluorescence 405nm is being utilized.
8. Calibrate the spectrophotometer and label the cuvette that was used for the calibration as "1" with a piece of tape.
9. Pour turmeric solution into the cuvette until cuvette is ¾ filled, and seal it with a lid.
10. Place it inside the cuvette, ensuring that the smooth sides do not have any fingerprints on them (if they do, clean it with a paper towel), and make sure the light hits the smooth side of the cuvette (not the rough side, as that can alter the reading).
11. Press "collect" and wait for 10 seconds before pressing "stop."
12. Using the "auto scale" and "analyze" features on the software, find the wavelength when with maximum fluorescence and record the maximum fluorescence.
13. Repeat steps 8-12 for all five replicates.
14. Repeat steps 1-12 for all five trials.

NOTE: When using solid dodecanol, it needs to be converted into liquid dodecanol. To do this, place a small beaker onto a hot plate and add the dodecanol into the beaker so it melts. When it seems like enough is melted, add onto a graduated cylinder to obtain accurate measurements, and see if more dodecanol is necessary.

NOTE: When reusing cuvettes for five other trials, the cuvettes may be stained from the turmeric, and it is essential to calibrate the spectrophotometer each time for all replicates.

Safety, Ethical, Concerns:

The experiment followed the Workplace Hazardous Materials Information System (WHMIS). Safety training was obtained before this investigation, providing information on the safe use and disposal of chemicals. Since alcohol and turmeric are organic compounds, they were disposed of in a separate waste beaker instead of a sink. To avoid confusion in handling the waste afterwards, all organic waste and its volume were recorded on paper and given to the chemistry teacher. The waste was accumulated and stored in a safe organic waste can.

Additionally, since water cannot clean turmeric stains, beakers were rinsed with ethanol. To limit the amount of ethanol used, the ethanol in cleaning was stored in a small beaker and reused to clean the cuvettes before going into the waste beakers. This ensured efficient use of ethanol.

Although three trials are ideal in a chemistry internal assessment, the average cuvette requires almost 4mL of solution, meaning that three trials required 12mL, and an extra 4mL in case a trial does not work out or if spillage occurs. However, psychologically and because the beaker only marked at 20mL intervals, it made best sense to use 20mL of solution and conduct five trials instead of three, allowing for efficient use of the solution.

UV light is also dangerous when nearby, so glasses and gloves were worn. Many individuals were working on their assessment during this, so whenever lights were closed, permission was asked so people were aware of the dangers of walking in the dark.

Table 2: The Hazards and Risks of Chemical Compounds and How Risk is Prevented (Fisher Scientific, 1999)

Chemical	Risk(s)	Prevention Procedures
Turmeric	**Safe;** inhaling large amounts of turmeric or going inside your eyes can irritate. Can also stain clothes and skin	- Wear goggles, gloves and a coat/ old clothes when working with turmeric. - Store alcohols in a cool, ventilated area. - Minimize skin and eye contact with alcohols and UV light. - Avoid skin contact and clean spills promptly. Dispose properly.
Methanol	**Moderate;** Flammable, poisonous, health hazard	
Ethanol	**Moderate;** Flammable, Poisonous, Health Hazard	
1-pentanol	**Moderate;** Flammable, Poisonous, Health Hazard, Environment	
Octanol	**Moderate-High;** Flammable, Health Hazards, Environment, Poisonous	
Dodecanol	**Moderate;** Flammable, Environment, Health Hazards, Poisonous.	

Analysis:

Raw Data:

Although relative polarity of all alcohols was difficult to find, the polarity directly depends on the dielectric constant, which is a substance/material's ability to store electric energy. Those with a higher dielectric energy are more polar. This also influences trends learnt in the *IB HL Chemistry* course and regards melting/boiling point and solubility in *Table 1*, where the alcohols with the lower dielectric constant have a lower solubility in water, a polar solvent. Melting points and boiling points are discarded because they depend on additional factors than only polarity. Polarity, in increasing order is **methanol, ethanol, 1-pentanol, octanol, dodecanol.**

Table 3: Physical and Chemical Properties of Alcohols, that determine their Polarity.

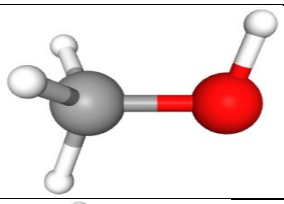
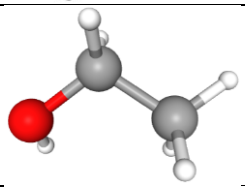
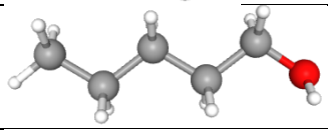
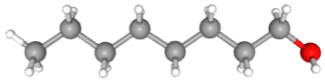
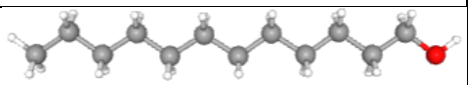
Alcohol	Chemical Structure	Dielectric Constant	Dipole-Dipole Moment	Solubility Properties
Methanol		32.60	1.70	Miscible with water at 25°C: 1000 mg/mL
Ethanol		24.50	1.69	Miscible with water at 25°C $1x10^6$ mg/L
1-pentanol		13.90	1.7	Miscible with water at 25°C: 22 000mg/L
Octanol		10.30	1.76	Miscible with water at 25°C 540mg/L
Dodecanol		6.50	1.60	Miscible with water at 25°C: 4mg/L

Table 4: Maximum Relative Fluorescence Intensity[1] (±0.001) *and Wavelength* (±0.01) *at Which Fluorescence Occurs*

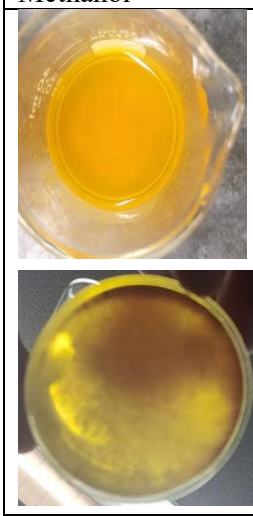
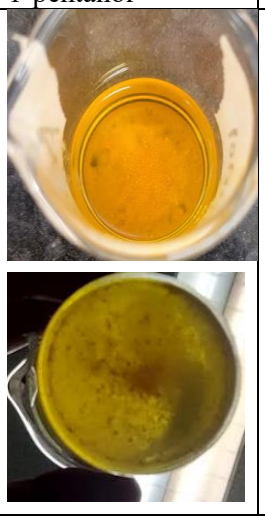
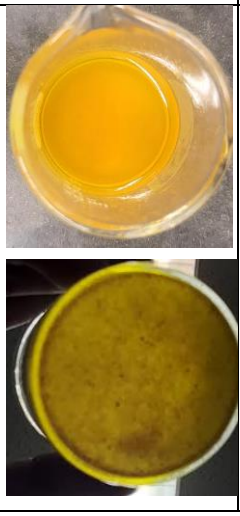
	Methanol	Ethanol	1-pentanol	Octanol	Dodecanol
Trial 1	0.019 (562.8nm)	0.020 (550.7nm)	0.024 (545.6nm)	0.024 (540.9nm)	0.024 (538.5nm)
Trial 2	0.019 (564.5nm)	0.022 (550.0nm)	0.023 (550.3nm)	0.030 (544.8nm)	0.024 (538.5nm)
Trial 3	0.021 (558.0nm)	0.021 (556.6nm)	0.024 (548.0nm)	0.023 (548.0nm)	0.023 (543.2nm)
Trial 4	0.021 (554.3nm)	0.020 (559.0nm)	0.022 (547.2nm)	0.026 (550.3nm)	0.023 (545.6nm)
Trial 5	0.018 (560.3nm)	0.022 (551.3nm)	0.024 (543.2nm)	0.025 (549.5nm)	0.022 (545.6nm)

Table 5: Raw Data of Fluorescence Wavelength from Light Spectrometer (±1.00)

	Methanol	Ethanol	1-pentanol	Octanol	Dodecanol
Trial 1	567 nm	558 nm	555 nm	556 nm	549 nm
Trial 2	565 nm	558 nm	560 nm	553 nm	544 nm
Trial 3	559 nm	559 nm	561 nm	550 nm	550

Qualitative Observations:

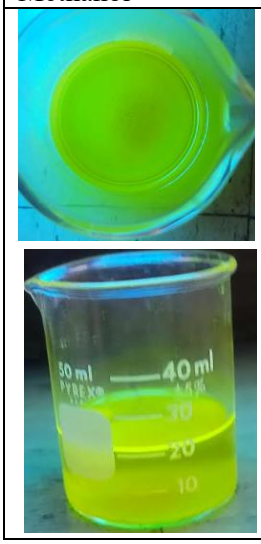
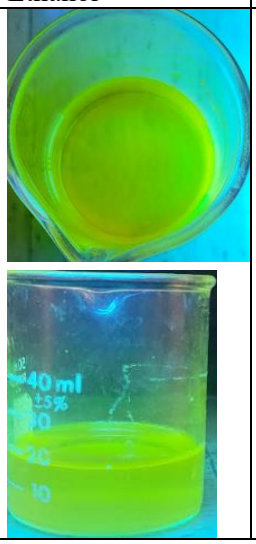
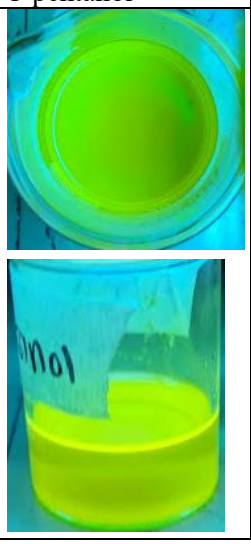
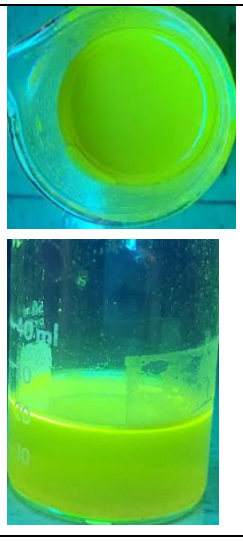
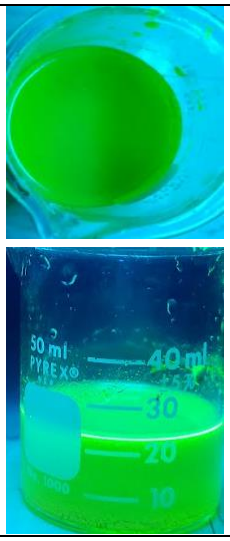
Table 4: Turmeric Solution Without UV light (Top View and Bottom View)

Methanol	Ethanol	1-pentanol	Octanol	Dodecanol
				

- Methanol, ethanol and 1-pentanol appear clearer, and the bottom of the beaker is visible.
- There are more scattered particles as the alcohol carbon number increases.
- Surprisingly, 1-pentanol appears the clearest and has the least amount of turmeric residue.
- Dodecanol has then patches or rough texture/pattern and is barely visible.
- Although their colour looks relatively the same, the colours of methanol, ethanol, and 1-pentanol appear more orange, whereas octanol and dodecanol appear more yellow.

[1] Intensity is called “relative fluorescence” as it is relative to the measurements or a reference measurement taken by the instrument (in this case, the spectrophotometer) (*BMG LABTECH, n.d*). Relative fluorescence has no units.

Table 5: Turmeric Solutions in the Presence of UV Light (top view and side view)

Methanol	Ethanol	1-pentanol	Octanol	Dodecanol
				

- The 1-pentanol appears to be the brightest in the presence of UV light than ethanol.
- They all have similar yellow-golden hues, except dodecanol, which has a greener colour. The residue in the bottom of ethanol is visible with a dark spot on it, while in the other ones, the dark spots are not as visible.

Processed Data:

The raw intensity values were combined to form an average, as shown below:

Table 6:Sample Calculation of Average Fluorescence Intensity of Turmeric in Alcohol (no units)

Calculation	Uncertainty
$= \frac{0.019 + 0.019 + 0.021 + 0.021 + 0.018}{5}$ $= 0.020$	$\frac{0.001 + 0.001 + 0.001 + 0.001 + 0.001}{5}$ $= 0.001$

Table 7: Average Relative Fluorescence of the Turmeric in Samples of Alcohol (no units)

Methanol	Ethanol	1-pentanol	Octanol	Dodecanol
0.020 ± 0.001	0.021 ± 0.001	0.023 ± 0.001	0.026 ± 0.002	0.023 ± 0.001

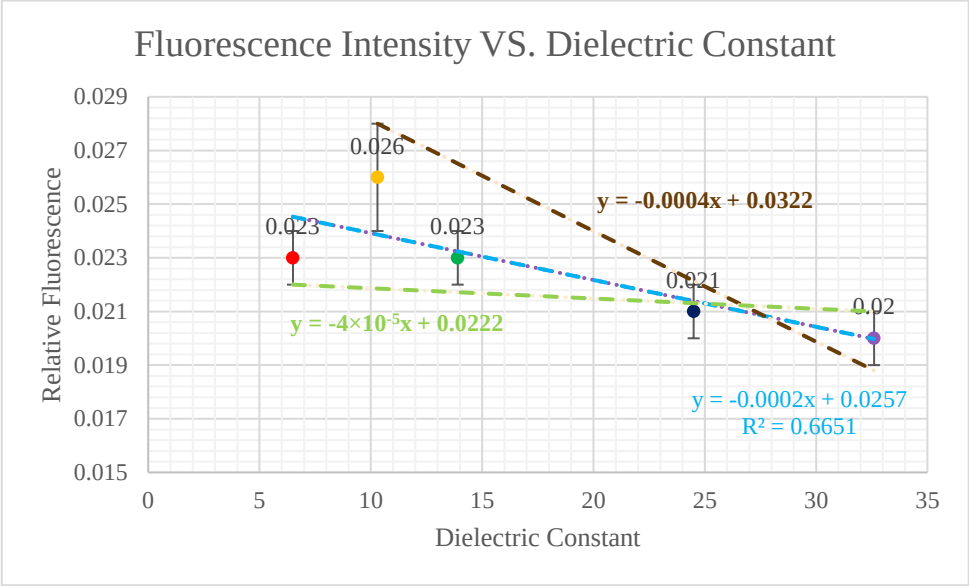
The standard deviation is chosen over the average uncertainty because it gives a more accurate visualization as to actual the spread of data about the average. Additionally, this process was conducted with the fluorescent intensity, because it was found surprising how the numbers were similar, but the wavelengths changed, and I thought it would be valuable to investigate this.

Table 8: Average Fluorescence Wavelength of Turmeric in Different Samples of Alcohol (nm)

Methanol	Ethanol	1-pentanol	Octanol	Dodecanol
560.0 ± 3.6	551.3 ± 6.0	546.9 ± 2.4	547.5 ± 3.5	542.3 ± 3.2

Instead of polarity, graphs of fluorescence intensity and the dielectric constant were chosen because of their interdependence with each other. A linear trendline (in blue) was deemed ideal because it has the highest R^2 value, meaning that the linear model aligns with the data.

Graph 1: Relative Fluorescence Intensity VS. Polarity (Measured Using the Dielectric Constant)



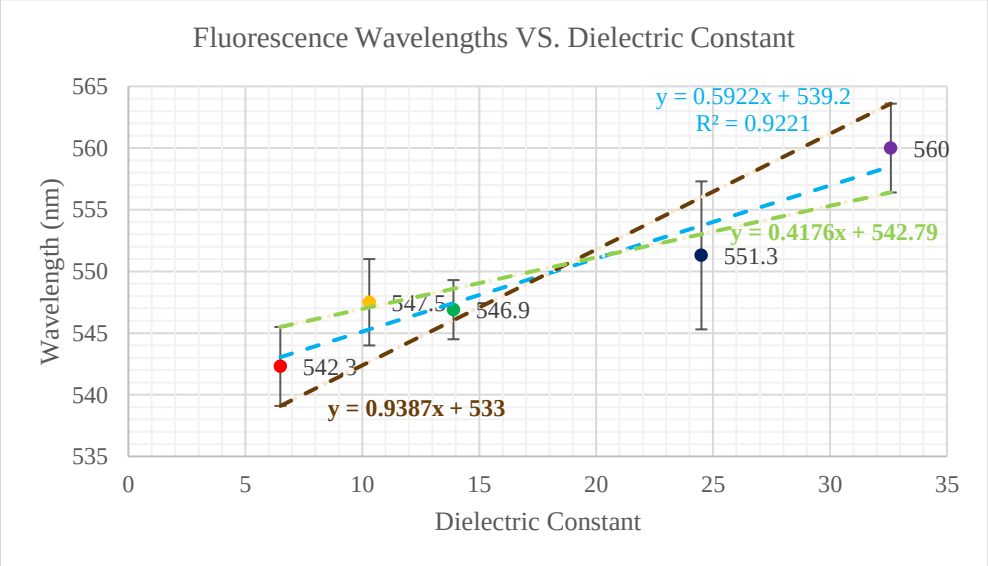
To find slope uncertainty, Excel's LINEST function was used, where (A1:A5) are the y values, and (B1:B5) are the x values (dielectric constant). The "const." value of 1 is so the line does not go through the origin, since it is apparent there is a y-intercept. The input is shown below:

Image 4: LINEST function input on Excel to Determine Slope Uncertainty and Results Obtained Results

```
=LINEST(A1:A5,b1:b5,1,1)
```

Slope	-1.7×10^{-4}
Uncertainty	7×10^{-5}

Graph 2: Fluorescence Wavelength VS. Polarity (Compared Using the Dielectric Constant)



Slope	0.593
Uncertainty	0.099

Conclusion and Evaluation:

The correlation between alcohol polarity and relative fluorescence is $-0.0002 \pm 7 \times 10^{-5}$ enforcing negligible correlation between fluorescence intensity and polarity. Meanwhile, there is a correlation between polarity and the wavelength at which fluorescence occurs, as the slope is and the correlation between fluorescence wavelength and polarity is 0.5922 ± 0.099. Although this contradicts the predicted hypothesis regarding fluorescence intensity, it supports the idea that

polarity plays an influence in energy emission and fluorescence properties. The average wavelength at which turmeric in ethanol, the most common solvent of turmeric, fluoresces is 551.3 $\pm$ 6.0 nm, providing a range of wavelengths between 545.3-557.3 nm. The literature value of the average wavelength at which it becomes excited is 526 nm (Mondal et al., 2000), meaning that the experimental value is higher than the expected range, indicating systematic errors in the experiment, assessed using percent error calculations below:

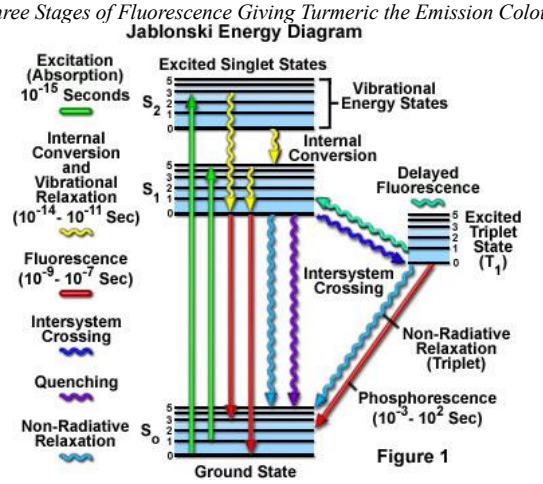
$$\% \, error = \left|\frac{551.3 - 526}{526}\right| \times 100\% = 4.80\%$$

The systematic errors are because the wavelength at which an electron in turmeric gets excited is approximately 526nm, many authentic sources state that "fresh wet turmeric rhizomes" often show emission bands "at 571 nm" which would make our range much lower, suggesting that the condition of the turmeric (whether it is in large chunks or small granules, it is dry or wet, old or new) can impact fluorescence, although it may not impact the polarity, and although this variable was held constant because the same turmeric was used and was not tampered with in any way before this experiment, it was something that was not known about until this experiment. Furthermore, although its fluorescence emission can be visible anywhere between 430nm to 600nm, allowing for the answer to be acceptable in that range (Krishnamoorthy et al., 2017).

There appear to be some random errors as the standard deviation of the experimental values (intensity and wavelength) are lower than or equal to 1%, but percent slope uncertainties and maximum/ minimum lines are large, at 35% for fluorescence intensity and 16% for the wavelength uncertainty, indicating low confidence and possibly no correlation to fluorescence intensity. With technology, uncertainty and human errors were minimized, proving a strength for the experiment.

In Fluorescence, three phases must occur: excitation, vibration, and emission. The excitation phase is where an electron ascends from the ground state to a higher energy level. Upon reaching higher energy, it gradually descends the vibrational energy states (mentioned in *Image 3*) before returning to the ground state in the form of fluorescence, which is the emission spectrum and is what is seen. The emission spectrum wavelengths provide a larger wavelength because there is a loss in vibrational energy, and lower energy causes larger wavelengths. (Herman et al., n.d).

Image 5: Diagram Illustrating the Three Stages of Fluorescence Giving Turmeric the Emission Colour it Has (Herman et al.)



The famous hydrogen atomic spectrum experiment done by Bohr, states that energy levels have discrete energy, this can explain why the wavelengths of each replicate are similar. The polarity of a fluorophore, which is an object that predictably re-emits light after being excited, influences how easily a molecule can be excited or not to the solvent. Solvents like alcohol, have dipole moments that surround the dipole moment of the fluorophore (the curcumin) and interact with it, creating longer wavelengths. When the electron is in the vibrational energy state, it loses its energy to the solvent molecules as it relaxes and starts the emission process. The solvent molecules then re-orient themselves, through a process called **solvent relaxation,** which lowers the energy separation between the ground and excited states, allowing for larger wavelengths of emission. However, since the dipole moments in these alcohols are similar, this could mean that they face the same energy when being emitted.

To improve this exploration, a comparison between functional groups like **esters** (not a **carboxylic acid** as turmeric is a weak acid and acids cannot react with acids) should be made, as they have different polarities than alcohols, while also being organic compound. Besides that, it would be beneficial to invest in fluorometers of the emission after the excited state, as they are more specific and sensitive to the emission. A spectrophotometer bases fluorescence on the absorbance due to lighting; whereas fluorometers select the excited and emission wavelength since an electron becomes excited at one wavelength. Other limitations are listed in *Table 11*.

Table 9: Possible Limitations of the Experiment Causing Inaccuracy in the Experiment, and Possible Solutions

Limitation/ Weaknesses	Effect and Magnitude on Result	Suggested Improvement
The alcohol during experiments evaporated, increasing the concentration of turmeric.	Although it is not possible how much evaporated, it would cause the colour of turmeric to intensify and there would be more residues left in the bottom of the container/cuvettes, and this would lead to a significantly higher wavelength since there is excess turmeric in the solution	Clear wrapping can be put over the solutions so the moisture on the wrapping can indicate the amount of alcohol lost and any changes in concentration from one experiment to another.
] The dodecanol was not able to absorb enough turmeric because of its solid state.	As the dodecanol cooled, *Table 5* shows bits of dodecanol resolidifying This can cause turmeric being trapped in the solid state, and not being used for the fluorescence, potentially causing a noticeably lower fluorescence intensity and longer wavelength.	Although liquid dodecanol is unavailable, immediately placing all the dodecanol in cuvettes with a lid can prevent cool air from solidifying the alcohol, while allowing it to reach partial and constant room temperature

An assumption made during this experiment was that the pH was constant throughout the experiment and that there were no other factors that impacted the fluorescence of the turmeric (a weak Bronsted-Lowry base). In experiments done with Pyranine, Fluorescein, and Tinopal, fluorescence increases as pH increases (Zhu et al., 2005). Although pH was not changed, these alcohols have many different properties, like solubility and pH, and an alcohol's amphoteric nature could cause the pH of turmeric in the solution to change, leading to a proportional change in fluorescence intensity. However, it is difficult to control this variable significantly because diluting the substances causes decreased concentration and lower fluorescence.

Additionally, it is assumed that the phone provides adequate accuracy in the wavelengths and colours, because it is ultimately an app working from sensors and perspective, and it can change on the type of phone quality and the saturation.

The maximum intensity for emission that occurs is 476nm at UV light (Ali et al, 2019). It is possible that although the spectrophotometer gives accuracy in fluorescence from blue light which fits the range, it is inadequate in determining the full intensity of the turmeric. From the experiment, light intensity was found using an optical fibre which had UV light shine on it. An optical fibre specifically shows the emission spectrum wavelength (Vernier, n.d) and how much the solution emits based on its light source (O'Kane, n.d). It was found that in many of the alcohol solutions, the maximum light intensity was at 476nm. However, this was not used during experimentation as it was initially uncertain whether the technique measured fluorescence. The results are shown below:

Image 6: Annotated Apparatus Setup Using an Optical Cord in the Dark

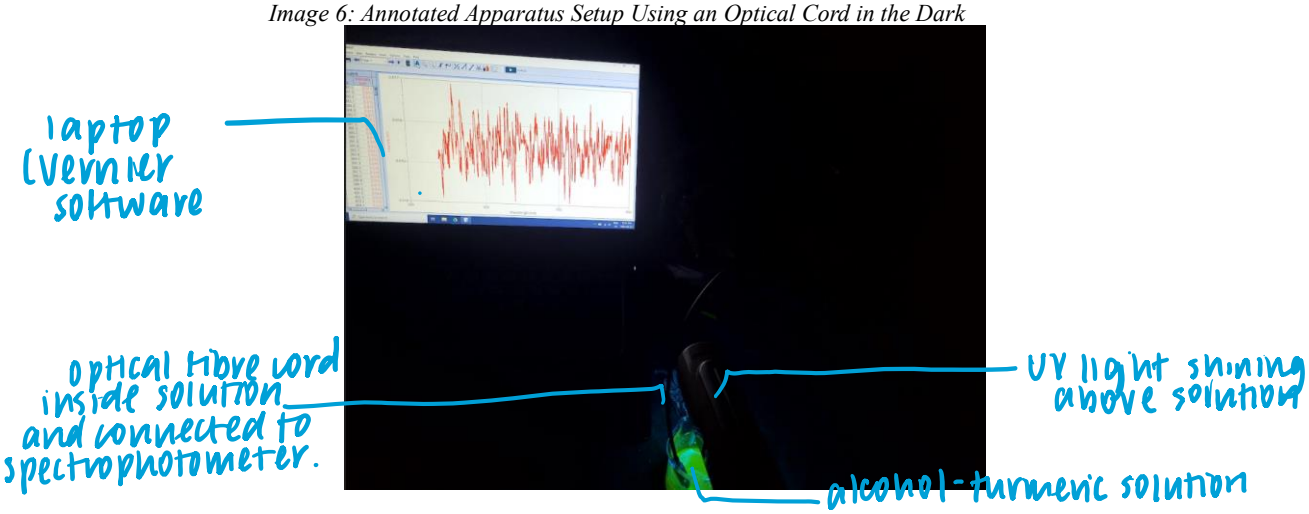


Table 10: Raw Data from the Optical Fibre Experiment (nm)

Methanol	Ethanol	1-pentanol	Octanol	Dodecanol
600.0 ±0.1	405.0± 0.1	601.4 ±0.1	461.0 ±0.1	421.6 ± 0.1

Some strengths in this experimentation include the **various techniques consulted upon experimenting, including pixelation, optical fibres and spectroscopy** to note any differences, and to assess the advantages and disadvantages with each method, allowing for the best method to be chosen; the use of technology minimizing any human errors or uncertainty; and the ability to make the practical experiment somewhat relevant and aligned with the theory. Furthermore, calibrating the spectrophotometer each time, although time-consuming, helped ensure the data was fairly accurate and any old alcohols were not interrupting the data. Five replicates were done for each trial to ensure redundancy in data.

As an extension, it would be beneficial to investigate why turmeric is more soluble in ethanol than methanol, considering methanol has a greater polarity than ethanol. Answering this question can provide insight into any unaccounted variables or forces contributing to fluorescence.

Nonetheless, this investigation, in a fun manner, solves the initial problem regarding the colour intensity of turmeric in starch (a carbohydrate), upon the addition of salt. If polarity plays a role in fluorescence but and causes the yellow colour to intensify, then adding more salt to turmeric and rice (a starch), should cause the yellow pigment to stick better and produce a brighter pigment (hypothesis formed while neglecting the salinity stress affecting curcumin).

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