**Background:** Turmeric powder is an inexpensive yellow-orange spice that is used to give some brands of mustard a bright yellow color. This color derives principally from curcumin (1, 2).

![Chemical Structures](image)


**Review Questions:**

1. Apply what you know about conjugated $\pi$-bonding systems to explain why the maximum absorbance wavelength for the keto-enol tautomer 1 should be longer than that for diketone 2.

   **Answer:** UV/Vis spectroscopy measures the wavelength of absorption necessary to excite an electron from the HOMO to the LUMO of a conjugated system. The conjugated system in keto-enol tautomer 1 is longer than the system in diketone 2, where the system is disrupted by an $sp^3$-hybridized methylene unit (CH$_2$). The more conjugated the $\pi$-bonding system, the less energy is required to excite an electron from the HOMO to the LUMO of this system, so keto-enol tautomer 1 absorbs lower energy, lower frequency, longer wavelength light.

   Associated learning objective: *Explain* how UV/Vis spectroscopy provides evidence that increasing conjugation of a $\pi$-system results in a decrease in the HOMO / LUMO gap for that system.

2. There has been some debate in the scientific literature about whether the keto-enol tautomer 1 or diketone 2 predominates at neutral pH~7. If the calculations for the maximum absorbance wavelength are correct, which of these compounds do you see on the initial yellow paper? Why might that compound be more stable?

   **Answer:** When light of a particular wavelength is absorbed, your eye detects light of the complementary color. In this case, the detected light is yellow, so the absorbed wavelength is between 400 and 440 nm. The keto-enol tautomer (1) is expected to absorb in this wavelength range. The keto-enol tautomer (1) may be more stable because it incorporates a strong internal hydrogen bond, and an extended conjugated system.

   Associated learning objective: *Relate* UV/Vis spectroscopy to visual perception.
Recall: When light is absorbed, your eye detects the complementary color.

<table>
<thead>
<tr>
<th>Wavelength of light</th>
<th>Complementary Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Violet: 400 - 420 nm</td>
<td>Yellow</td>
</tr>
<tr>
<td>Indigo: 420 - 440 nm</td>
<td>Yellow</td>
</tr>
<tr>
<td>Blue: 440 - 490 nm</td>
<td>Orange</td>
</tr>
<tr>
<td>Green: 490 - 570 nm</td>
<td>Red</td>
</tr>
<tr>
<td>Yellow: 570 - 585 nm</td>
<td>Indigo &amp; Violet</td>
</tr>
<tr>
<td>Orange: 585 - 620 nm</td>
<td>Blue</td>
</tr>
<tr>
<td>Red: 620 - 780 nm</td>
<td>Green</td>
</tr>
</tbody>
</table>

3. In principal, water can affect the interconversion of keto-enol tautomer 1 and diketone 2. Draw arrow-pushing mechanisms using water to interconvert 1 and 2.

Answer:

Associated learning objective: Explain why the $\alpha$-protons to carbonyls are acidic, and how this property leads to enolate formation, and racemization and epimerization of $\alpha$-stereogenic centers

Watch the video of the procedure (https://www.youtube.com/watch?v=0afSRiCzBco) and carefully observe what happens. Then, respond to the below questions, which require you to draw on your observations and your knowledge of organic synthesis.

In the video, a series of solutions were prepared by adding to water one of the following:
(a) A teaspoon of baking soda (sodium bicarbonate, NaHCO$_3$). Assume a solution pH~9.
(b) Vinegar, which contains acetic acid (CH$_3$CO$_2$H). Assume this solution has a pH~2.
(c) Concentrated household bleach, which contains NaOCl. Assume a solution pH~13.
(d) Water. Assume this solution has a pH~7.
4. If the calculations and experimental values for the maximum absorbance wavelength are correct, which compounds could be responsible for the red color in the paper? See below for possible structures.

Answer: When light of a particular wavelength is absorbed, your eye detects light of the complementary color. In this case, the detected light is red, so the absorbed wavelength is between 490 and 570 nm. Compounds 4, 5 and 6 each include at least one phenolate anion, and are expected to absorb in this wavelength range.

Associated learning objective: Relate UV/Vis spectroscopy to visual perception.

5. Draw an arrow-pushing mechanism to explain why the baking soda solution transformed the yellow paper to red paper. What is the role of baking soda in this reaction?

Answer: Baking soda is a base in this transformation. The red color may arise from the presence of compound 4 or 5, so mechanisms have been provided to access both of these compounds. The pH of baking soda will produce very little of the trianionic compound 6, so it is unlikely that the red color originates because of the presence of 6.
Associated learning objective: Explain phenol reactivity, with particular attention to phenol acidity.

6. Draw an arrow-pushing mechanism to explain why the vinegar solution transforms the red paper to yellow paper. What is the role of vinegar in this reaction?

Answer: Vinegar includes acetic acid, which is an acid in this transformation.

Associated learning objective: Explain phenol reactivity, with particular attention to phenol acidity.

7. Why doesn’t the vinegar solution cause the yellow paper to change colors?

Answer: Vinegar contains acetic acid, which is acidic, and cannot be used to generate a phenolate anion. The phenolate anions are red, but the other involved species are not.

Associated learning objective: Explain phenol reactivity, with particular attention to phenol acidity.
8. After exposure to the bleach solution, the initially yellow paper becomes red and then eventually becomes colorless. Speculate about why the paper changes from red to colorless. Chemically, what might this process entail?

**Hints:**

8a. All of the depicted structures are in dynamic equilibrium, so if one of these structures is present, there is likely to be some small amount of all of the others (which would mean that if any of these compounds was present, the sheet of paper might remain colored).

8b. Pretend that reactivity starts with compound 2 for this question.

Answer: UV/Vis spectroscopy measures the wavelength of absorption necessary to excite an electron from the HOMO to the LUMO of a conjugated system. The conjugated system in colored compounds 1, 3–6 is longer than the system would have to be in a colorless compound. A retro-aldol reaction would be capable of fragmenting this extended system, and compounds in dynamic equilibrium could eventually proceed through similar fragmentation pathways. If this reaction proceeds, one might imagine that hydroxide would attack the electrophilic carbon of the carbonyl system in an initial nucleophilic addition reaction.

Associated learning objective: Draw detailed arrow-pushing mechanisms for retro-aldol reactions.

9. Write 1-2 sentences to explain what you have learned from this worksheet.

10. Was this exercise useful? Why or why not? Provide 1-2 suggestions to improve this worksheet.

The initial draft of this worksheet was prepared by Tanya Thomas, Miranda Allen, Gilbert Brooks, III, Bashir Adeed (2015) to accompany their procedural video. It has been adjusted by Prof. Jennifer Roizen and Mr. Mina Shehata (2016).