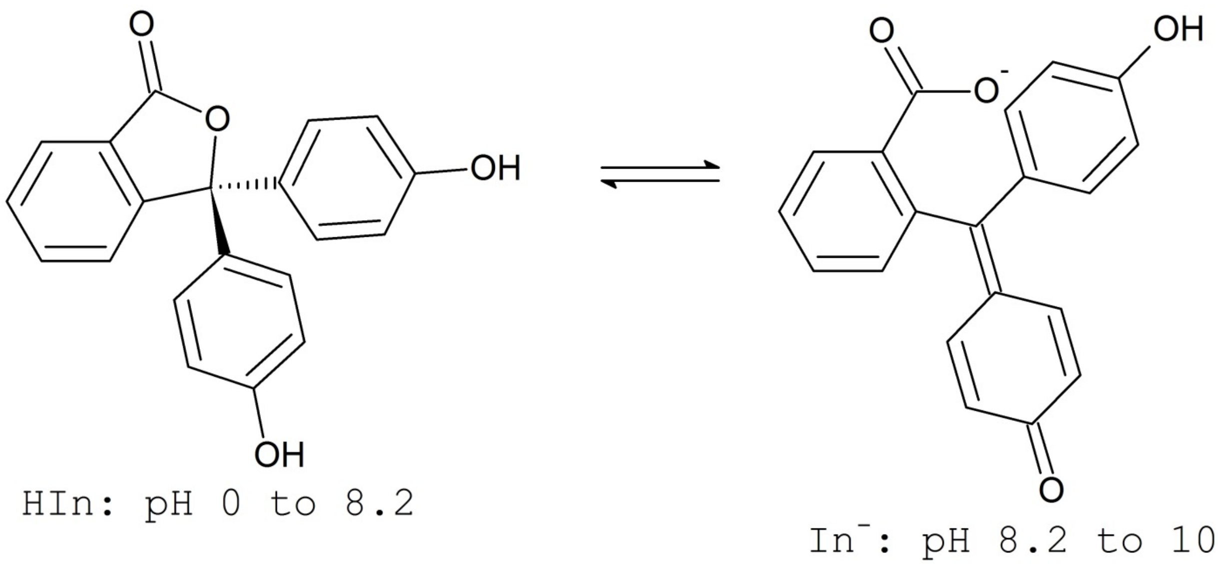
# Equilibrium

In this experiment you will determine the equilibrium constant $K_a$ for the reaction of phenolphthalein, which is a weak acid, with water.

$$HIn + H_2O \rightleftharpoons In^- + H_3O^+$$




Here HIn is the protonated form of phenolphthalein and $In^-$ is it's conjugate base. HIn is colorless and $In^-$ has a bright pink color.

You will do this two different ways. One way will be to vary the $[H_3O^+]$ and calculate $K_a$ at different pH's, taking the average. The other way will be to plot pH vs. $\log\frac{[In^-]}{[HIn]}$ and find the equation of the best-fit straight line. The y-intercept will be $-\log(K_a)$. That is, you will use the Henderson – Hasselbach equation:

$$pH = pK_a + \log\left(\frac{[A^-]}{[HA]}\right)$$

where $pK_a = -\log(K_a)$. This is the equation of a straight line with the y-intercept being $pK_a$.

## CHEMICALS

You will need about 15 mL of the phenolphthalein solution, about 20 mL of each of 6 different pH buffer solutions, labeled C, D, E, F, G, & H.

You will need an additional 20 mL of solution C(a total of about 40 mL of that solution).

## EQUIPMENT NEEDED

You will need six large test tubes. You will need a combination of small beakers and Erlenmeyer flasks for a total of 7 containers. You will also need a 10 mL graduated cylinder, a 25 mL graduated cylinder, a LabQuest with a pH probe and the colorimeter, and a cuvette for the colorimeter. You will need Kimwipes and Q-tips.

## WASTE DISPOSAL

The phenolphthalein solution should go in the organic waste container.

## SAFETY

Goggles should be worn for the entire experiment. The phenolphthalein solution is toxic if ingested. The phenolphthalein solution contains ethanol which is flammable; keep it away from all sources of ignition.

## PROCEDURE

### Solution Preparation

Label the beakers/Erlenmeyer flasks as C, D, E, F, G, H, and blank.

Record the molarity of the stock phenolphthalein in your data table.

Into each beaker/flask add 2.0 mL of the phenolphthalein solution (using the 10 mL graduated cylinder) and 18.0 mL of the appropriate buffer solution (using the 25 mL graduated cylinder). Swirl to mix. In the beaker/Erlenmeyer flask labeled "blank" add 2.0 mL of ethanol and 18.0 mL of buffer C. Swirl to mix.

**Absorbance Measurement**

Set the wavelength of the colorimeter to 565 nm.

Make sure your cuvette is clean and dry.

Using the blank solution, zero the colorimeter. Clean and dry your cuvette with a Kimwipe and a Q-tip.

Measure the absorbance of each solution (C, D, E, F, G, & H). Record each absorbance in your data table.

Clean and dry your cuvette between each measurement.

**pH Measurement**

Measure the pH of each of the first 5 solutions (C, D, E, F, & G) in large, clean, and dry test tubes. Record these in your data table.

**CALCULATIONS**

You will calculate the equilibrium constant $K_a$, at five different pH's, and take the average of these. You will also find $K_a$ by plotting pH vs. $\log \frac{[In^-]}{[HIn]}$, the y-intercept is $-\log(K_a)$.

$$K_a = \frac{[In^-][H_3O^+]}{[HIn]}$$

The buffer solutions keep the $[H_3O^+]$ constant. By measuring the pH of each solution you can find the $[H_3O^+]$ by:

$$[H_3O^+] = 10^{-pH}$$

You can find $[In^-]_{eq}$ for each of the solutions from Beer's law:

$$A = \epsilon \lambda c$$

Here A is the absorbance you read from the colorimeter, c is the $[In^-]_{eq}$, $\lambda$ is the distance the light travels through the solution (this is the inside width of your cuvette that you measured), and $\epsilon$ is the molar extinction coefficient.

First you will need the product of the molar extinction coefficient, $\epsilon$ and the path length, $\lambda$. That is, $\epsilon\lambda$. For this you will use solution H. This solution is so basic that we can neglect any phenolphthalein in the form HIn and assume it is entirely in the form $In^-$. That means that the $[In^-]_{eq} = [HIn]_0$ (for solution H only).

For the other solutions calculate the $[HIn]_{eq}$. You can do this by:

$$[HIn]_{eq} = [HIn]_0 - [In^-]_{eq}$$

since for every molecule (or mole) of $In^-$ that is produced one molecule (or mole) of HIn is consumed.

You will need to calculate $[HIn]_0$. Since you diluted the stock phenolphthalein by the same factor each time, you need only perform the dilution calculation once ($C_1V_1=C_2V_2$).

To find $\epsilon\lambda$, solve Beer's law for $\epsilon\lambda$ for solution H:

$$\epsilon\lambda = \frac{\mathrm{A}}{\mathrm{c}}$$

c is $[In^-]_{eq}=[HIn]_0$ in mol/L, and A, which has no units, is the absorbance you measured for solution H.

Once you know $\epsilon\lambda$ you can use Beer's law to find $[In^-]_{eq}$ for the first 5 solutions (C, D, E, F, & G). Rearrange Beer's law to find c:

$$\mathrm{c} = \frac{\mathrm{A}}{\epsilon\lambda}$$

$[In^-]_{eq}$ = c from the above equation, $[HIn]_{eq} = [HIn]_0 - [In^-]_{eq}$, and you get $[H_3O^+]$ from your pH measurements.

Calculate $K_a$ for each solution (C, D, E, F, & G) by plugging these values into

$$K_a = \frac{[\mathrm{In}^-]_{eq}[\mathrm{H_3O^+}]}{[\mathrm{HIn}]_{eq}}$$

Find the average of these values.

Next, have a spreadsheet calculate $\log \frac{[In^-]_{eq}}{[HIn]_{eq}}$ for each solution, plot pH vs.

$\log \frac{[In^-]_{eq}}{[HIn]_{eq}}$, draw the best-fit straight line, and get the equation of this line.

Include this graph and equation in your calculations section.

The y-intercept of the line is $-\log[K_a]$, or $pK_a$. Calculate $K_a$ by taking $10^{pK_a}$ ($10^{\text{y-intercept}}$).

**CONCLUSION**

Report your value for $\epsilon\lambda$ at 565nm.

Report your two $K_a$ values: the average of the $K_a$'s for the different solutions and the one from the graph.

List at least one possible source of experimental error, the effect it would have on your result (be very specific) and why they it have that result.