Colorimetry on the cheap

Colorimetry is simply the measurement of colour. Simple visual colorimetry is familiar to anyone who has been involved with maintenance of a swimming pool and use of the human eye to determine the intensity of a coloured solution is much more accurate than is generally thought: that said, it is not possible to get a really *accurate* measurement of just how intense a colour is or how cloudy a solution may be.

As a technique of huge importance in chemistry, colorimetry is one of the most widely used methods for quantitative chemical analysis. Unfortunately, it is not used as widely in schools as it should be, largely due to cost. In this article, we will show you how to construct a workable colorimeter for use throughout the school for the cost of only a few pence.

Figure 1 - Visual Colorimetry.

A colorimeter is a device that passes light of a particular wavelength through a sample. Using a detector, the colorimeter can measure how much of the light passes through the sample. We can then calculate the amount of light absorbed by the sample and this is related to the concentration of the chemical of interest. This way it is possible to obtain numerical values for the amount of light transmitted and, given such data, there is much more that can be done.

Why bother making one?

1) **Cost** - Even with a cheap model, a class set is the best part of £1,000. If it is possible to make a working colorimeter for a few pounds then it means that this important technique can be used more often.
2) **Access** - Making a colorimeter for a few pounds means that it is possible for each pupil to use one and thus everyone gets to use and understand the technology.
3) **Understanding** - If you can make something, you are likely to have a clearer understanding of how it works. It ceases to be some sort of 'magic box' that just mysteriously gives you the answer.

The basics

At its most basic, a colorimeter needs a light source that shines through a cuvette and some way of measuring the intensity of the light that passes through.

- For our light source, we are using an LED.
- For the light detector, we are using a light dependent resistor (LDR)
- And the housing for these is simply a block of polystyrene, cut to shape and size with appropriate holes made using a cork-borer.

Making your colorimeter

You will need: A piece of polystyrene, 1 x rubber bung, a Cork borer (no 7 or 8 depending on the diameter of the bung), 1 x LDR, 1 x white 5 mm LED, 1 x 180 ohm resistor, 1 short piece of insulated wire.

1) Cut a piece of the polystyrene to approximately 5 cm x 5 cm. A hot knife is the most effective method for this as it provides a firm, non crumbly edge.

Figure 2 *- Cut block of Jablite board.*

2) Select a rubber bung/cork-borer combination that allows the bung to fit in the hole made by the borer.

3) Cut the length of the bung in half, with a knife or scalpel, and keep the narrower end.

Figure 3 *- Cut bung and LED.*

4) Use the cork-borer to make a hole horizontally completely through the block. Take care to keep it as horizontal as possible.

Figure 4 *- Horizontal hole for LED and LDR.*

5) Use the borer again to make a hole vertically down from the top, taking care to make sure it crosses the line of your first hole. Don't take this hole all the way through to the bottom.

Figure 5 *- Vertical hole for cuvette.*

6) Check the size with a cuvette - you may need to press on the sides of the hole with a spatula. The idea is that it is a snug fit and the cuvette does not rotate (Using a warm spatula will help square off the hole).

Figure 6 *- Sizing for the cuvette.*

7) Insert the LED into the hole in the bung. Push it into the hole in the block to make sure it fits.

Figure 7 *- Testing the fit of the LED.*

8) Repeat with the LDR.

Figure 8 *- Testing the fit of the LDR.*

9) Use a hot knife or spatula to cut a slit for a filter.

Figure 9 *- Cut a slit for the filter.*

10) Cover the whole block with one or two layers of aluminium foil (to lightproof it). Pierce where the holes are with a screwdriver or pencil and push the foil in.

Figure 10 *- Wrap in aluminium foil.*

11) Bend the arms of the resistor 90 degrees.

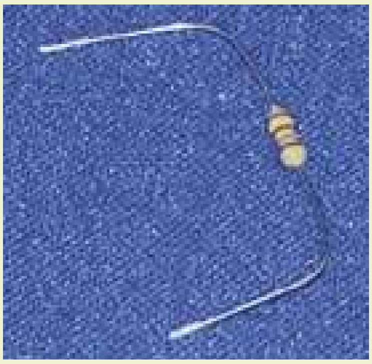

Figure 11 - Bend the arms of the resistor.

Figure 13 - The finished device.

12) Take the insulated wire and use it to connect the positive arm of the LED (the longer one) to one arm of the resistor.
13) Gently push the bung into one of the holes on the side of the block.

14) Push the arms of the resistor into the polystyrene block.

Figure 12 - Push the resistor into the block and connect to the LED with wire.

15) Connect the positive terminal of the power supply to the resistor and the negative to the LED and switch on briefly to make sure it lights up.
16) Gently push the LDR into the hole opposite the LED.
17) Connect the arms of the LDR to the Multimeter and select resistance - pick the range that gives you a good value (20 kΩ usually on the ones we are using here. (Figure 13)

Using your colorimeter

1) Put your sample in a cuvette.
2) Place it in the hole in the top.
3) Take a lid from a drinks bottle and use that as a cap over the cuvette to prevent stray light entering.
4) Switch on the LED and the multimeter.
5) Take the reading on the multimeter.

The detector in your colorimeter is a Light Dependent Resistor (LDR). When a light shines on it, the resistance is reduced. You are using a multimeter to measure the resistance of the LDR. Commercial colorimeters give you a choice of measuring either transmittance or absorbance.

- **Transmittance** is a measure of how much light passes through; the highest value is when a blank cuvette is used.
- **Absorbance** is a measurement of how much light is absorbed and in this case the blank cuvette will give a low reading.

In this colorimeter, the more light gets through (the more transparent the solution) the lower the reading. Thus it is measuring absorption rather than transmittance.

You can use this simple device in much the same way as a 'proper' colorimeter for instance:

a) Plotting a standard curve and using it to work out concentrations.
b) Following the course of a reaction to determine its rate.

Colour Adjustment

While many experiments can be carried out quite satisfactorily using white light, many are much better using a more restricted colour range. There are two simple ways to adjust the design to allow for this.

1) Filters - Use a heated knife to melt a narrow slit in the foam block

Figure 14 - Filters.

between the LED and the cuvette. You can then insert filters in here. If you are near a large-ish centre of population, then find a theatrical lighting supplier and you can pick up free swatch books of lighting gel filters. (The two main suppliers are Lee and Rosco) (You may have some of these filters already that you can cut up). Any coloured filters, cellophane for instance, will work. The advantage of the lighting gels is that each sample is on a backing card that gives you its absorption spectrum. An advantage this gives over the cheaper commercial colorimeters is that you have a far wider range of colours to choose from. (Figure 14)

There are two methods for choosing a suitable filter to use:

a) Examine the absorption spectrum and use a filter of a wavelength that is absorbed most.

To measure the concentration of carotenoids, the best filter would be one around 500 nm, which gives absorption by carotenoids and low by chlorophyll. (Figure 15)

b) A simpler method that will work for many coloured compounds is to use a colour wheel. This helps you determine the colour that is absorbed most from the colour you are seeing. Simply look at where the colour of your solution lies on the wheel and use a filter of the colour opposite it.

Figure 16 - A simple colour wheel.

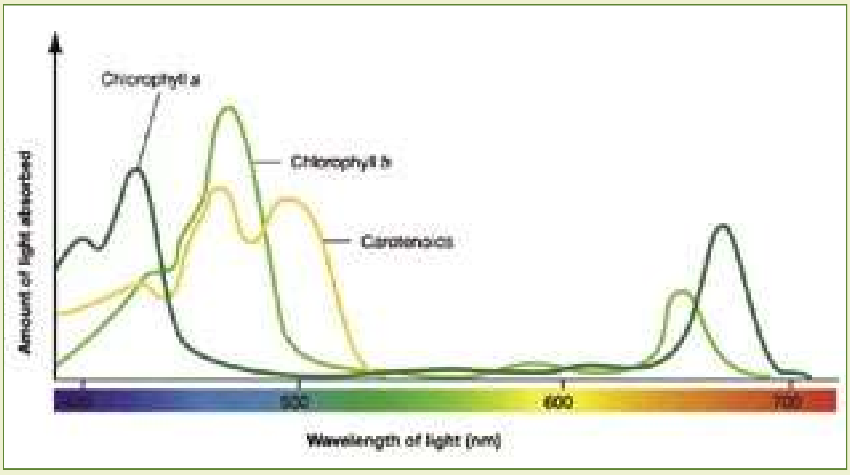

Figure 15 *- Absorption spectrum of chlorophyll and carotenoids.*

For instance, to measure the absorption by a copper sulphate solution you should use a yellow filter.

2) Alternatively, you can simply replace the LED with one of a different colour. This is the method used in several of the cheaper commercial colorimeters, you have a choice of Red, Green or Blue and your choice determines which LED is selected. It also highlights one of the advantages your new, home-made colorimeter has over all but the most expensive commercial ones. You have a much wider range. As well as visible light, it is possible to purchase LEDs that give out either Infra Red or Ultra Violet - both of which have been successfully tested. Standard cuvettes are still transparent in the near UV, down to about 340 nm so are quite suitable for this use.

Interpreting the data

In most cases, the figures for resistance can simply be used as they are. For instance, when determining concentration against a reference graph, a simple plot of resistance against concentration will be quite usable and enable you to read the resistance of an unknown off the scale.

The graph will often look neater if it starts from zero - in which case simply take the blank, calibration reading (which you should do anyway) and subtract this from each of the other readings - Excel or any other spreadsheet makes this a very easy task.

There are times when you might want to try to get more accurate data, in this case you will need to convert your resistance reading into the actual absorbance. From the Beer-Lambert Law, it is possible to work out that

$$A = \log_{10}\left(\frac{I_0}{I}\right)$$

Where I_0 is the intensity of light passing through the blank and I is the intensity of light passing through the sample

Once again, Excel can come to the rescue and make the calculation quite straightforward.

Once you have this value, you can use the Beer-Lambert law to work out other information you may need.

$A = \varepsilon l c$

Where

ε = the molar absorption coefficient of the substance (at that wavelength)

l = the length of the path through the solution (1 cm in a standard cuvette)

c = the concentration of the solution in mol dm^{-3}.

It is possible to link up the LDR to a datalogger and get it to automatically record the results but in the spirit of parsimony and participation, we have assumed that not many schools will have access to 20 dataloggers and so have concentrated on the simpler approach.

A more detailed treatment on interpreting the data will be appearing on our website.

Evaluation

This colorimeter is not quite as accurate as a commercial one but considering the difference in price that is perhaps to be expected. Nonetheless, quite good results can be obtained with a small amount of care.

a) Be careful in the construction to make sure the LED and LDR are aligned.

b) It is best to make sure that a single experiment/investigation is only carried out on one device as they may give slightly different results.

c) Similarly, as the brightness of the LED obviously varies with the input voltage you will need to make sure the same voltage is being used each time the colorimeter is used. If there is an ongoing investigation, it might be an idea to put a voltmeter into the circuit with the light.

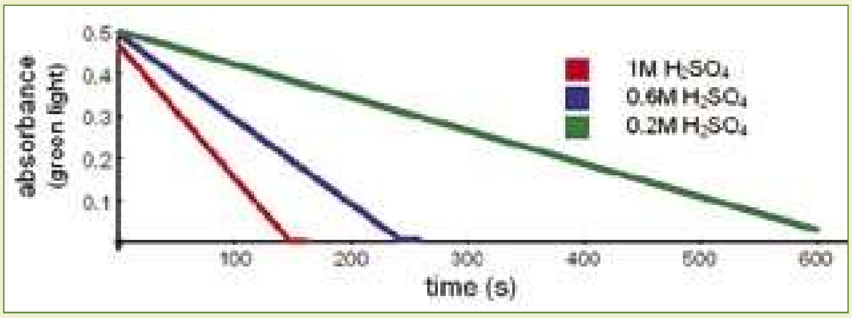

Figure 17 - *Iodination of propanone 1 (graph taken from Mystrica website).*

Here are some results obtained for the rate of reaction of the iodination of propanone with varying concentrations of acid.

A) Using a Mystrica colorimeter
(http://mystrica.com/Colorimeter.aspx)
(see Figure 17)

B) Using a home-made colorimeter
(see Figure 18)

Note - the value for the 1M acid is roughly twice as long as for the Mystrica graph - but we used HCl, not H_2SO_4 so the top graph has twice the concentration of hydrogen ions.

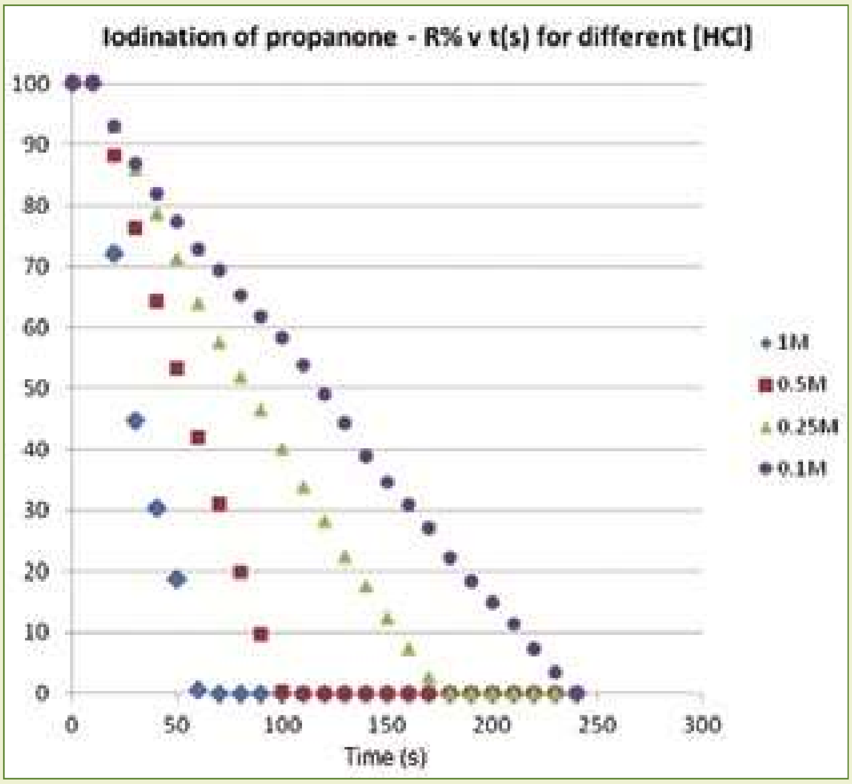

Figure 18 - *Iodination of propan-2-one (graph generated by Excel).*

Conclusion

This colorimeter is probably not accurate enough for use in an Advanced Higher project, though the construction and evaluation of such a device could be a possibility, but it will give an easy and cheap entry in to the very important topic of colorimetry and allow, we hope, for its much wider use in schools.

Supplies

Any LDR/LED combination should work. The ones we used (all were from RS components (http://uk.rs-online.com) were:

LDR	NORPS-12 TO18	£1.36
LED	5 mm White, Water Clear,15deg	£0.32
Resistor	CFR16 carbon film resistor,180R 0.25 W	£0.16 for 10

Polystyrene from any waste packaging can be used quite happily but we used Jablite insulation board from B&Q as it is dark grey and so there is less reflected light. (£15.98 for a board 50 x 1200 x 2400 mm)