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Analysing wine at school

European countries produce more than half of the world's wine – and drink a lot of it too! These hands-on activities for schools reveal the science behind the perfect wine.

By Thomas Wendt

The age at which it is legal to drink alcohol varies from country to country, but most teachers would agree that drinking wine during chemistry lessons is inappropriate (and potentially dangerous!). However, producing and analysing wine at school can be fun and educational. These activities, developed at the science centre Experimenta[w1], invite students aged 15-18 to become vintners for a day, using analytical techniques to explore the changes that take place during the wine-making process.

Wine is produced by fermenting grape juice (which has particularly high levels of sugar) using specialised yeast cells. The sugar is converted into ethanol and carbon dioxide under anaerobic conditions:

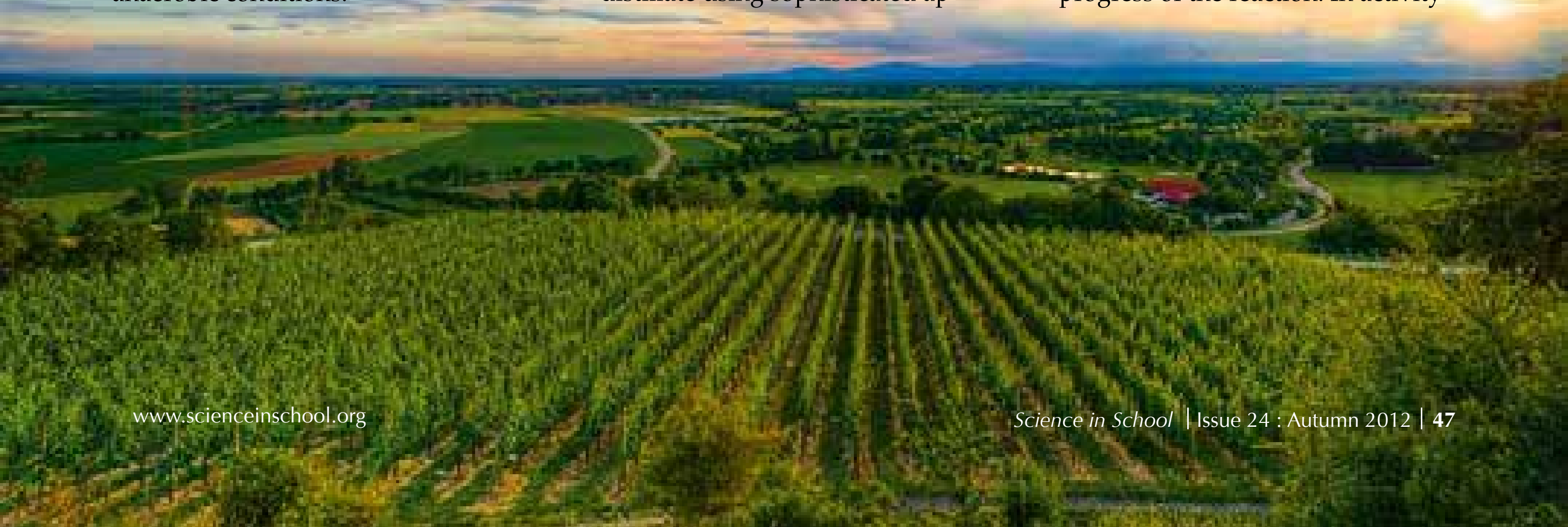
$$C_6H_{12}O_6 + 2\ ADP + 2\ P_i = 2\ C_2H_5OH + 2\ CO_2 + 2\ ATP$$

The three main factors that determine the quality of the final product are sweetness, alcohol content and acid content. Using standard methods of a commercial wine laboratory, these three activities for the school laboratory explore how the quality of the starting grape juice and the must (fermenting grape juice) affect the final product. Each activity takes approximately 20-30 minutes.

1. In activity 1, students can determine the sugar content of grape juice using refractometry. Activity 1a (see below) offers an alternative, based on density measurement.
2. The exact determination of the alcohol content in commercial wines is performed by distilling the ethanol, then measuring the viscosity of the distillate using sophisticated apparatus. In activity 2, students can use the equipment used by hobby winemakers – a vinometer – to measure the alcohol content of the must and wine.
3. A well balanced wine needs a certain amount of fruit acid; the total acid content is a very important measure, because it directly affects the flavour. In activity 3, the acid content is determined by pH titration.

Four further activities[w2] can be downloaded from the *Science in School* website:

- Activity 1a: in an alternative to activity 1, students determine the sugar content of grape juice using density measurement instead of refractometry.
- Measuring levels of carbon dioxide, one of the products of the fermentation, is a useful way to monitor the progress of the reaction. In activity



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Grapes fermenting to make wine

Barrels of wine being stored in a cellar to mature

4, students quantify CO_2 levels over the course of the reaction by literally shaking the gas out of solution.
- In activity 5, students use light transmittance to investigate the difference that fining (the addition of substances that clarify the wine by precipitation) makes to the cloudiness of the finished product.
- In activity 6, students examine fermenting yeast under the microscope.

To supply the must used in these experiments, you will need to set up a simple grape juice fermentation at least one day in advance, using red grape juice (e.g. from the supermarket). You will also need some basic chemistry laboratory equipment, plus a vinometer for measuring alcohol content, a pycnometer (also known as a specific gravity bottle) and a refractometer. A description of how to set up the fermentation can be found on the *Science in School* website[w2].

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Determining sugar content

The sweetness of the wine is determined by the amount of sugar remaining after fermentation, together with the total acidity of the wine. A dry wine has up to 9 g/l sugar and an acidity level that is at least 2 g/l lower than the sugar content. A medium-dry wine has a sugar content of 9-18 g/l and an acidity level that should be no more than 10 g/l lower than the sugar content. A sweet wine has 18-45 g/l of sugar. To ensure the correct balance of sugar, acidity and alcohol in the final wine, it is important to determine the starting sugar concentration; if necessary, limited amounts of sugar can be added before fermentation.

The increased density of the must (compared to water) is mainly due to fermentable sugar. Density measurements or refractometry can be used to measure the sugar content, which in Germany is expressed as the must weight and measured in Oechsle (°Oe). In the English-speaking world, the sugar content is expressed in Brix (°Bx), which represents the concentration of dissolved sugar, in weight percent (wt%).

The must weight is calculated by:

must weight = (density – 1) X 1000

Where must weight is measured in °Oe and density in g/l.

As a rough estimate, 1°Oe corresponds to 2.37 g/l sugar (i.e. about 0.237 °Bx). Therefore, the sugar concentration can be estimated as:

sugar concentration = must weight X 2.37

Where sugar concentration is measured in g/l.

The fermentation of all fermentable sugar in a solution of 100 °Oe (sugar concentration 237 g/l or 23.7 °Bx) yields approximately 100 g/l ethanol (or 10 wt% alcohol). Because ethanol has a density of 0.79 g/ml, this converts to 12.67 vol% ethanol. Thus:

alcohol concentration (in % volume) = alcohol concentration (in g/l) X 0.1267

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Student activity 1: determining sugar content using a refractometer

The amount of sugar in the grape juice will determine both the alcohol content and the sweetness of the finished wine. In this activity, you will use the refractive index to estimate sugar content.

Refraction is the change in direction of light when it passes from one medium to another (e.g. from air into water). The light-scattering behaviour of a solution changes as the concentration of solutes (dissolved substances) increases. A refractometer uses this principle to determine the concentration of dissolved particles in a solution. In wine, these are principally sucrose.

Most handheld refractometers give the concentration of the dissolved substance either in Brix (°Bx), a scale defined in terms of sucrose content, or in Oechsle (°Oe). A solution of 20 wt% sucrose in water is 20 °Bx. Oechsle can be converted approximately into Brix by multiplying by 0.237.

Image courtesy of Experimenta

Figure 1: Refractometer and scale

Materials

- Refractometer
- 20 wt% sucrose solution
- Grape juice
- Paper towels
- Pipette

Procedure

1. Pipette 2 drops of the sucrose solution onto the glass surface of the refractometer and close the lid.
2. Take a reading through the eyepiece and enter the data in table 1.
3. Using a paper towel soaked in distilled water, clean the glass surface, and then dry it.
4. Repeat the measurement with grape juice.
5. Calculate the missing numbers in table 1 using the equations above.

Questions

1. How accurate was your result for the sucrose solution compared to the expected value?
2. How reproducible were your measurements? Compare them to that of other groups.
3. If you carried out activity 1a as well, how comparable were your results for the two methods (density versus refractometry)?
4. A typical wine has about 12 vol% alcohol. Estimate how much sugar needs to be added to the grape juice to obtain 12 vol% alcohol.

	20 wt% sucrose	Grape juice
Must weight (°Oe)		
Sugar concentration (°Bx)		
Possible alcohol yield (vol%)		

Table 1: Calculation of sugar content of samples

Image courtesy of Maksud_kr / iStockphoto

Chemistry

Student activity 2: determining alcohol content

The amount of alcohol obtained by fermentation depends on the sugar content of the grape juice and the alcohol tolerance of the yeast strain: most yeast strains tolerate up to 16 % alcohol. The amount of alcohol can be measured quite accurately using a vinometer, a simple device developed for hobby winemakers. It is based on the principle that the surface tension falls as the alcohol content increases.

In this activity, you will measure the alcohol content of your must.

Materials

- Coffee filter
- Funnel
- Beakers
- Must
- Wine
- Vinometer
- Pipette
- Paper towels
- Distilled water

Procedure

1. Filter 20 ml must through a coffee filter to remove any remaining yeast cells.
2. Place a small amount of filtrate in the funnel of the vinometer (figure 2B) and wait until the capillary is full. Keep the remaining filtrate for activity 3.
3. Carefully invert the vinometer onto a layer of paper towels, then observe the level of liquid while it slowly drops (figure 2C). Once it stays constant, take a reading and enter it in table 2.
4. Rinse the vinometer with distilled water, then repeat the measurement using the wine.

Note: The alcohol content of the must is probably much lower than that of the wine. This may be because the fermentation process is not finished. It can also indicate that remaining sugar has increased the surface tension and is affecting the reading.

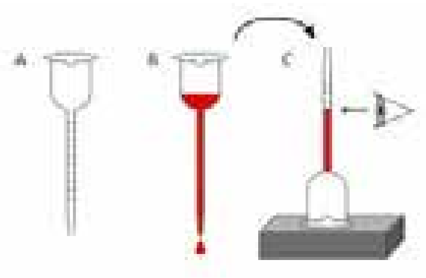


Image courtesy of Experimenta

Figure 2: Using the vinometer

Questions

1. You determined the sugar concentration of the grape juice in activity 1. Based on the available sugar in the grape juice, did you expect a higher alcohol content in the wine?
2. If the fermentation continued for longer, would you expect an increased alcohol content?

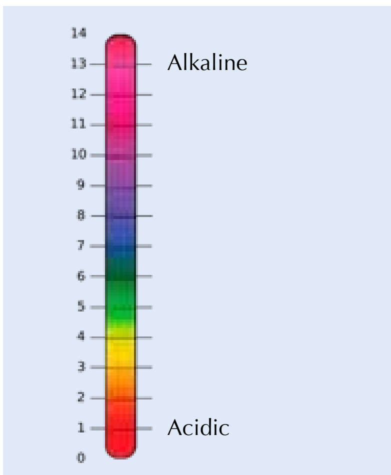
	Alcohol content (vol%)
Must (filtered)	
Wine	

Table 2: Alcohol content determined with a vinometer

Total acid content

Fruit juices can contain several different acids, including tartaric, malic, citric and oxalic acid, in differing ratios, depending on the type of fruit. The predominant acid in wine is tartaric acid, which has a pH between 3 and 4. However, due to the complex mixture of different acids and bases, proteins and salts, the total acid content of wine cannot be estimated from the pH value alone. Instead, it is determined by titration to neutrality and expressed as total equivalent amount of tartaric acid in g/l. The acid content of wine is typically 4-8.5 g/l but can be as high as 15 g/l. It must always be considered in conjunction with the amount of remaining sugar (see 'Determining sugar content').

Tartaric acid (molecular weight 150 g) is a diprotic acid (containing two hydrogen atoms per molecule that can dissociate in water as protons) that can be fully neutralised with sodium hydroxide. Because 1 mol NaOH neutralises 0.5 mol tartaric acid (75 g/l), 1 ml 0.1 M NaOH neutralises 7.5 mg tartaric acid.



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$$HOOC\text{-}CH(OH)\text{-}CH(OH)\text{-}COOH + 2NaOH \rightarrow Na^+\text{-}OOC\text{-}CH(OH)\text{-}CH(OH)\text{-}COO^- Na^+ + 2H_2O$$

Chemistry

Student activity 3: Determination of acidity by titration

All wines contain a certain amount of acid. The winemaker is interested in the total acidity, caused mainly by tartaric acid. The total acidity is determined by titration with diluted sodium hydroxide.

Materials

- pH meter
- Magnetic stirrer
- Beaker (250 ml)
- Two measuring cylinders (10 ml, 100 ml)
- Burette
- NaOH solution (0.1 M)
- Distilled water
- 10 ml must (filtered, from activity 2)
- 10 ml wine

Image courtesy of Experimenta

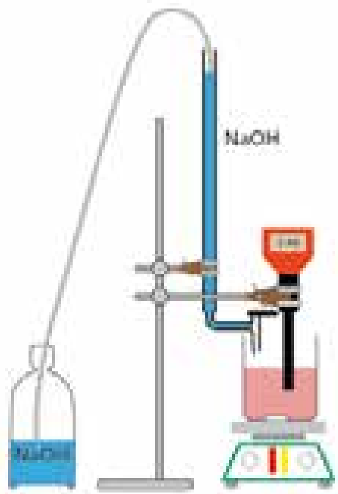

Figure 3: Set-up of the titration experiment

	Must	Wine
pH at start		
Starting volume NaOH (ml)		
End volume NaOH (ml)		
Volume NaOH used (ml)		
Concentration of acid (g/l)		

Table 3: Determination of the total acidity

Procedure

For each sample (must or wine):

1. Fill the burette with NaOH solution. Enter the starting volume in table 3.
2. Measure 10 ml of your sample and place it in the 250 ml beaker. Add 100 ml distilled water.
3. Start the magnetic stirrer and insert the pH electrode so that the tip is in the sample, but not touching the sides of the beaker or the magnetic stirrer flea.
4. Add NaOH solution dropwise until neutral pH is reached. Take a reading on the burette and enter it in table 3.
   - Did you observe any colour changes?
   - If so, at what pH value?
   - What could be the reason for a colour change?
5. Calculate the amount of NaOH used and the acid concentration.
   Example: We used 14 ml 0.1 M NaOH to neutralise 10 ml solution. The concentration is therefore (14 x 7.5 mg/ml x 100) = 10.5 g/l acid.

Safety note: Wear safety goggles and gloves. See also the general safety note on the *Science in School* website (www.scienceinschool.org/safety) and on page 65.

Questions

In activities 1-3, you analysed the three major factors that determine the quality of the final product: sweetness, alcohol and acid content. Now it is time to evaluate your product.

1. Is the total acidity within the limits for wine production?
2. Did the starting grape juice contain sufficient sugar to produce the expected alcohol content?
3. How long would you expect fermentation to take before the process is finished?

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Acknowledgements

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Web references

w1 – Visit the Experimenta website: www.experimenta-heilbronn.de

w2 – The following materials can be downloaded from the Science in School website (www.scienceinschool.org/2012/issue24/wine#resources):

- Instructions for preparing the materials – ideally at least a week in advance
- Activity 1a: to determine the sugar content of grape juice using density measurement
- Activity 4: to quantify CO_2 levels over the course of the reaction
- Activity 5: to use light transmittance to investigate the difference that fining makes to the cloudiness of the finished product
- Activity 6: to examine fermenting yeast under the microscope.

Resources

A basic guideline for common experiments in wine analysis:

Schmitt A (1975) *Aktuelle Weinanalytik, Ein Leitfaden für die Praxis.* Germany: Heller Chemie. ISBN: 978-3-9800498-3-2

For a comprehensive overview of topics that are relevant to the hobby winemaker, see the Fruchtweinkeller website (www.fruchtweinkeller.de; in German) and the Fruchtwein website (http://met-und-fruchtwein.de, also in German)

If you found this activity useful, why not browse the other teaching activities in *Science in School*? See: www.scienceinschool.org/teaching

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BACKGROUND

Experimenta

Experimenta[w1] in Heilbronn is the largest informal learning and interactive science centre in southern Germany. In addition to the interactive exhibitions and science garden, Experimenta offers more than 30 laboratory-based programmes for school classes and individual pupils, from kindergarten level up to upper secondary school. These programmes address technology and all life sciences as well as providing teacher training.

Thomas Wendt received his PhD on structural biology from the European Molecular Biology Laboratory (EMBL) in Heidelberg, Germany, in 1998. During his postdoctoral research in the USA and back in Germany, he then focused on protein biochemical and molecular biology methods. After supervising numerous students, Thomas decided to concentrate on encouraging young people to consider a scientific career. Since 2009, he has been the educational head of the teaching laboratories at Experimenta.

To learn how to use this code, see page 65.