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scottish schools education research centre

STEM bulletin

supporting STEM for all Local Authorities through advice, ideas and inspiration

NO. 267 - SUMMER 2019

β-galactosidase: Competitive inhibition

In the past few years the Biology Team at SSERC have published details of several enzyme assays which could be used to support Higher Biology and Higher Human Biology; such enzyme systems include phosphatase [SSERC, 2015], catalase [SSERC, 2018], and β-glucosidase [SSERC, 2015].

Figure 1a - β-galactosidase catalyses the following reaction.

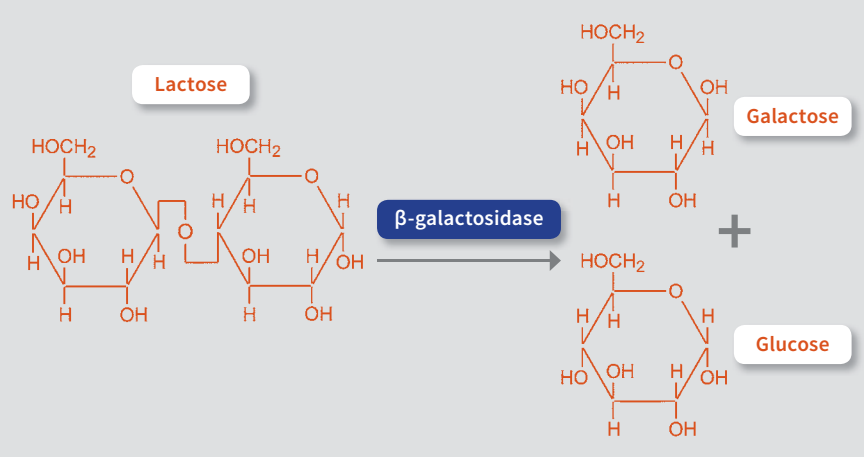


Figure 1b - β-galactosidase catalyses the following reaction.

The most recent SQA Course Specification documents [SQA, 2019] for Higher Biology and Higher Human Biology both contain the suggestion that one of the Learning Activities which students might follow is to 'Carry out *experiments on the effect of inhibitors on reactions. Examples could include the inhibition of β-galactosidase by galactose and its reversal by increasing ONPG concentration'.* Interestingly neither specification suggests Learning Activities which involve non-competitive inhibitors.

In this article we explore an activity which sets out how one might assay β-galactosidase and study the effects of a competitive inhibitor.

The enzyme system

The enzyme β-galactosidase catalyses the reaction as shown in Figure 1a. In more detail this can be represented as seen in Figure 1b.

Galactose acts as an inhibitor of the forward reaction and in this capacity can be described as a feedback inhibitor.

ONPG (o-nitrophenyl β-D-galactopyranoside) also acts as substrate for the enzyme, see Figure 2a. In more detail this can be represented as seen in Figure 2b.

Galactose acts as a competitive inhibitor of the enzyme, competing with ONPG for the active site. At high galactose concentrations the reaction of β-galactosidase with ONPG will be supressed because >>

Figure 2a - β-galactosidase catalyses the following reaction.

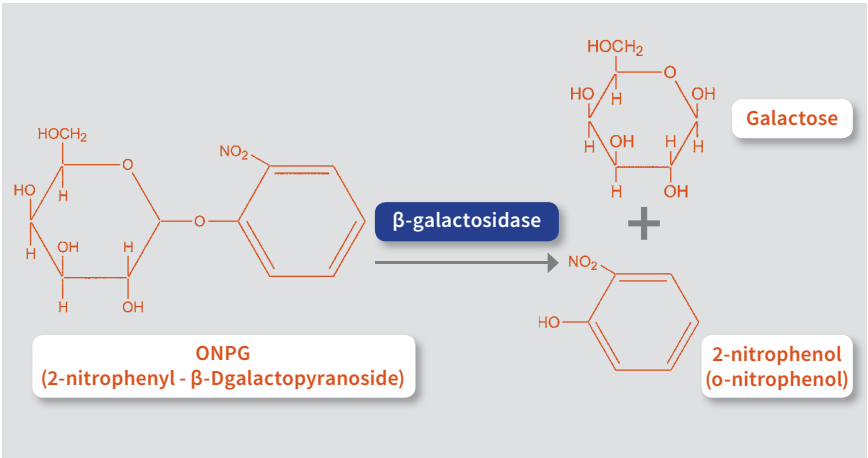


Figure 2b - β-galactosidase catalyses the following reaction.

of competition for the active site. This inhibition can be overcome if the ONPG concentration is sufficiently increased.

Experimental design

In common with many enzyme-based practicals, the inhibition of β-galactosidase offers huge scope for students to become involved in the process of experimental design. On the SSERC website (see https://www.sserc.org.uk/subject-areas/biology/higher-biology/enzymes/) we have provided a detailed protocol for the experiment (this includes a Technical Guide) as well as a PowerPoint which we use when running this practical as part of CPD sessions. The protocol on the website has all the steps laid out in a prescriptive manner. However, we believe that there is scope for students to be shown the basic technique (i.e. the mixing of colourless solutions of β-galactosidase and ONPG leading to the formation of coloured o-nitrophenol) and invite them to produce an experimental plan for how they might show that the reaction is competitively inhibited by galactose. At one level one might just add galactose and show that the rate of colour formation is slowed or stopped; the formulation of a detailed, robust protocol which allows for the generation of quantitative results, accompanied by suitable controls, is by contrast a demanding exercise.

We use *Lactase* (Lactozym); from the National Centre for Biotechnology Education as our source of enzyme.

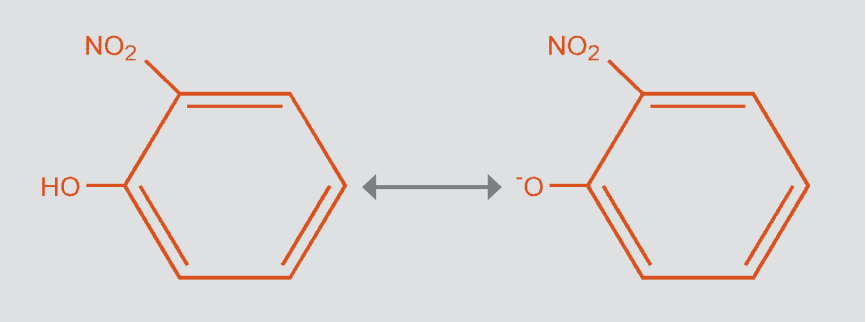


Figure 3 - in solution o-nitrophenol, the product of the reaction, exists in 2 forms viz the protonated form (which is colourless) and the anionic form (which has a yellow colour).

If kept refrigerated the enzyme maintains its declared activity for 6 months or longer. Whilst the optimum pH for activity is reported [National Centre for Biotechnology Education, 2019] to be 6.5 the protocol suggests that experiments be carried out in buffer at pH 8.0. The reason for this difference is that in solution o-nitrophenol, the product of the reaction, exists in 2 forms *viz* the protonated form (which is colourless) and the anionic form (which has a yellow colour), see Figure 3.

The pK_a for the equilibrium shown is 7.2 (http://www.zirchrom.com/organic.htm). In solutions at pH 7.2 equal amounts of the protonated and anionic forms will be present. In order to take advantage of the coloured nature of the anionic form (i.e. making it easier to follow the reaction colorimetrically), the enzyme assay is carried out at pH 8.0 where the majority (some 80+%) of the o-nitrophenol will be in its coloured form.

Tube	20% galactose in buffer (cm^3)	ONPG stock (cm^3)	Buffer (cm^3)
1	2	0.2	0.8
2	2	0.4	0.6
3	2	0.6	0.4
4	2	0.8	0.2
5	2	1.0	0.0

Table 1 - Solutions as prepared.

Steps in the protocol

All solutions, (apart from the 'working enzyme solution' see step 1 below), are prepared in pH 8.0 buffer. A stock solution of ONPG at a concentration of 2.8×10^{-2} mol dm^{-3} is prepared in buffer (pH 8.0).

1) Preparing a diluted enzyme solution of suitable activity

The first stage in the protocol is to produce a 'working enzyme solution'. 10-15 drops of the *Lactase* stock are diluted with distilled water (approximately 20 cm^3).

2) Testing enzyme activity

A solution (3 cm^3) is prepared which contains buffer (2 cm^3, pH 8.0, 0.1 mol dm^{-3}) and ONPG (0.5 cm^3, 2.8 x10-2 mol dm^{-3}). Working enzyme solution (0.5 cm^3) is added and the absorbance of this mixture is measured after 2 minutes. What you are looking for is an absorbance change after 2 minutes of between 0.3 and 0.5. If the activity of the working enzyme solution is too low (absorbance <0.3) then its concentration needs to be increased; if too high (absorbance >0.5) then the working enzyme solution needs to be diluted.

3) Measuring the effect of increasing ONPG concentration (the substrate) on β-galactosidase activity in the presence of a constant concentration of galactose

Solutions as prepared are shown in Table 1. >>

In turn 0.5 cm^3 of the working stock enzyme solution is added to each tube and the absorbance measured after 2 minutes (wavelength of observation is in the range 420-450 nm depending on choice of colorimeter). Typical data are shown in Table 2 and plotted in Figure 4.

From the data in Figure 4 it can be seen that an increase in ONPG concentration leads to an increase in ONP concentration after 2 minutes incubation. This is taken as evidence that galactose on the active site of the enzyme can be replaced by increasing ONPG concentration in behaviour that is classically displayed by competitive inhibitors.

Extension work

- Investigate the rate of o-nitrophenol production by measuring absorbance changes at regular time intervals over a period of some 5-6 minutes (in the absence of an inhibitor).
- Investigate the effect of enzyme concentration on the rate of o-nitrophenol production (in the absence of an inhibitor).
- Investigate the effect of increasing concentration of galactose whilst keeping [ONPG] constant.
- Substitute glucose for galactose (the other product of the reaction) to see if it has an inhibitory effect on enzyme activity.
- Investigate the effect of a non-competitive inhibitor (I_2/KI) on enzyme activity - the protocol on the SSERC website has experimental details for this. <<

Tube	Final concentration of galactose (% w/v)	Final concentration of ONPG (mol dm^{-3})	Absorbance (450 nm)
1	11.4	1.6×10^{-4}	0.05
2	11.4	3.2×10^{-4}	0.11
3	11.4	4.8×10^{-4}	0.15
4	11.4	6.4×10^{-4}	0.23
5	11.4	8.0×10^{-4}	0.27

Table 2 - Typical data.

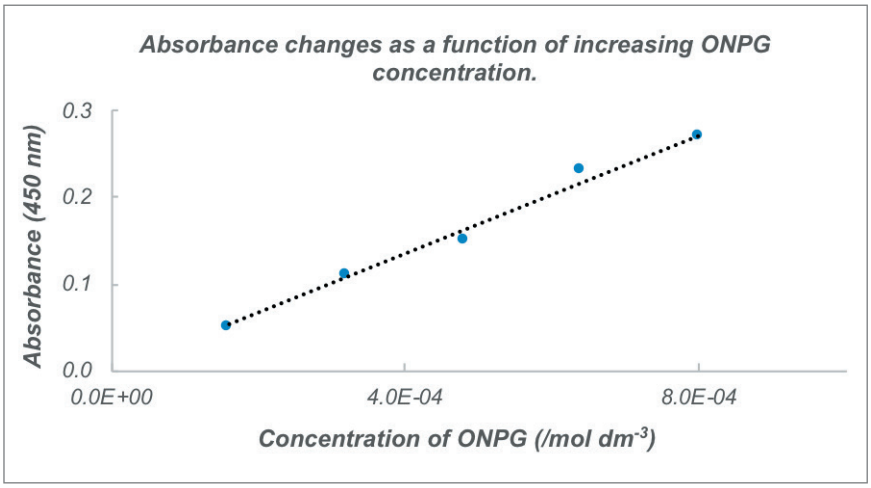


Figure 4 - Absorbance changes observed (450 nm) in solutions of increasing o-nitrophenyl β-D-galactopyranoside (ONPG) concentration in the presence of β-galactosidase and galactose (11.4% w/v). Further experimental details are given in the text.

References

- National Centre for Biotechnology Education (2019), *Lactase* (β-galactosidase). Details are available at http://www.ncbe.reading.ac.uk/MATERIALS/Enzymes/lactozym.html (accessed April 5th 2019).
- SQA (2019), Higher Biology and Higher Human Biology Course Specifications. These can be downloaded at https://www.sqa.org.uk/files_ccc/HigherCourseSpecBiology.pdf and https://www.sqa.org.uk/files_ccc/HigherCourseSpecHumanBiology.pdf respectively (accessed 25th March 2019).
- SSERC (2018), Catalase activity in immobilised yeast - effect of inhibitors, STEM Bulletin, **265**, 2-3.
- SSERC (2015), Fun with phosphatase, SSERC Bulletin, **251**, 6-8.
- SSERC (2015), Kinetic studies with β-glucosidase, SSERC Bulletin, **252**, 12-14.

ENTHUSE Celebration Awards

SSERC was delighted to host the Scottish ENTHUSE Celebration Awards 2019 [1] at the Engine Shed in Stirling on 14th May 2019. These awards celebrated excellence in STEM education in Primary & Secondary schools, in school leadership and for technicians and support staff. The event allowed SSERC to commend the commitment of the winners to professional learning and the impact that it has had on them, their pupils and their school.

All winners were invited to attend the National ENTHUSE Celebration event at the Royal Society in London in June 2019.

While the highlight of the event was the awarding of prizes, the day also included updates on the opportunities that SSERC supports and facilitates through a range of wider STEM engagement programmes.

Kevin McKeever, Manager of the STEM Ambassador programme in the east of Scotland provided an update, highlighting the wealth of knowledge and experience that is available to schools and community groups through this volunteer programme. It is noteworthy that in the findings of the Education Scotland STEM CLPL Survey Findings (June 2017) [2] this bank of approximately 6000 active individuals are regarded as key providers of professional learning for teachers.

From left to right in picture: Derek Boath, Monifieth High School (winner Excellence in STEM Teaching Secondary), Martin McKenna , Holy Cross Primary School (winner Excellence in STEM Teaching Primary), Angela Barclay, Monifieth High School (winner School Leadership in STEM), Alastair MacGregor CEO SSERC, Karthika Paranthaman, Boroughmuir High School (winner Excellence in STEM Teaching Technician), Mark McShane and Graham Armstrong, Kinross High School (Joint winners School Leadership in STEM), Heather Reid OBE.

In 2018/19 SSERC facilitated 22 STEM Insight placements, allowing teachers and technicians time in industry to gain experience about the world of work and potential employment opportunities that they could then share with pupils in their schools on their return. Such opportunities recognise that those in regular contact with young people can influence subject choices, future study options and career pathways. Whilst in a privileged position to inspire and direct, many recognise they do not always have the appropriate knowledge to do this effectively. Such placements provide the opportunity for educators to increase their own STEM capital. Helen Winton, Head of STEM Engagement SSERC provided an overview of these placements while contributions from Karen Alexander, STEM Manager Dumfries House and Sarah Morgan, Jacob's highlighted the benefits of teacher placements to businesses.

Heather Reid, OBE Meteorologist & Education Consultant provided an inspiring Keynote 'The importance of Excellent STEM Education' in which she highlighted how her passion for physics was kindled by an inspirational teacher. She emphasised how those in the teaching profession can inspire the questioning and inquiry skills in young people, thereby increasing their scientific literacy. She also shared the enjoyment she has had from being involved as a Polar Ambassador over the last 2 years, supporting the Polar Explorer Programme [3]. The build, launch and operation of RRS Sir David Attenborough brings an exciting context to the teaching of STEM subjects. The associated education programme encourages and supports schools that are keen to raise aspirations and attainment >>

in STEM and aims to inspire the next generation of scientists and engineers. 47 schools across Scotland have benefitted from this opportunity over the last 2 years.

Graeme Rough, Project Manager for the Young STEM Leader Programme provided an update on the development of this exciting opportunity. With a pilot currently underway, the programme will be available to all young people across Scotland in 2020 through school and community groups. The key aim of the Young STEM Leader (YSL) programme will be to facilitate the development of peer STEM role models to inspire more young people to develop an interest in STEM and pursue the study of STEM subjects and relevant future careers.

SSERC are very grateful to the Engine Shed who gifted the use of their facilities for this event. <<

References

[1] https://www.stem.org.uk/enthuse-celebration-awards.

[2] https://blogs.glowscotland.org.uk/glowblogs/STEMcentralinmotion/2018/08/27/stem-professional-learning-survey-2017/.

[3] https://www.stem.org.uk/welcome-polar-explorer-programme.

Microbiology in Schools Advisory Committee (MiSAC) - 50th Anniversary

To commemorate its 50th anniversary, the Microbiology in Schools Advisory Committee (MiSAC) has produced a series of short illustrated articles, aimed at secondary school teachers and students, but of interest to a wider audience. The MiSAC*matters* Anniversary Articles collection is introduced by a foreword from Sir Paul Nurse FRS and comprises over 30 articles written by leading microbiologists. To learn more about the amazing contributions of microbes to plant and animal health, how we might overcome the mountains of plastic waste or why pandemic 'flu is so deadly, visit www.misac.org.uk now and follow the links to the Anniversary Articles collection. <<

Enzyme activities for BGE

The Biology Team at SSERC has decided to have another look at some activities which we think might be suitable for the study of enzymes at BGE, or National 4 Biology, where learners are required to take part in practical activities which illustrate the, "…properties of enzymes and their use in industries" [1].

We believe that the experiments described are particularly useful for enzyme study with younger pupils for the following reasons:

- They provide a strikingly visual illustration of the degradation of starch by enzymes.
- They show that in the presence of barley grains starch is broken is down thus allowing learners to conclude that the enzymes responsible are present in living cells.
- They clearly demonstrate the effects of temperature and pH on enzyme activity.

The method uses diastase solution added to starch-agar in Petri dishes to demonstrate the breakdown of starch by diastase. The term 'diastase' could be misleading. 'Diastase' usually refers to a mixture of enzymes found in germinating barley seeds, principally α-amylase and β-amylase, which bring about the hydrolysis of starch to fermentable sugars. So, diastase is not the name of a specific enzyme; it could refer to any one of a group of plant amylase enzymes. However, it is reasonable for learners to describe diastase as plant amylase. For these experiments we used Alpha-amylase (*Termamyl*®) purchsed from NCBE [2].

A well is cut in the starch-agar using a cork borer. The well is filled with enzyme solution and left at room temperature. After 24 hours the dish is flooded with iodine solution which becomes blue-black except in the area around the well where the enzyme solution has diffused through the gel and has broken down the starch (Figure 1).

The technique can be used in variety of ways to demonstrate some properties of enzymes. Here we suggest three:

1) The effect of diastase solution is compared to the effect of germinating barley seeds and boiled germinating barley seeds.
2) A series of plates placed in different temperatures for 24 hours is used to investigate the effect of temperature on the activity of diastase.

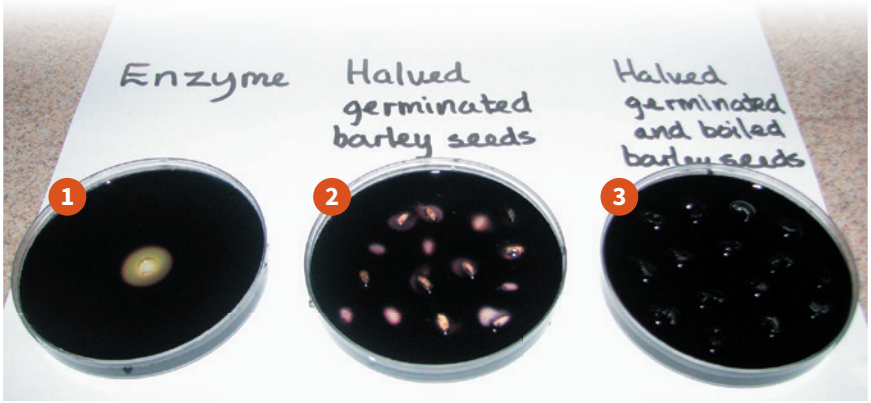


Figure 2

Figure 1 - The left hand well acts as a control by using distilled water instead of enzyme solution.

3) Diastase solution in a variety of pH buffers is used to investigate the effect of pH on the activity of diastase.

Activity 1 - Do barley seeds contain enzymes?

The aim of this activity is to provide a simple method by which pupils can conclude that diastase breaks down starch and that living cells present in germinating barley seeds produce the same substance (Figure 2). The seeds are soaked for 48 hours. Some of the seeds are boiled (for about 10 minutes). The seeds are halved and placed on top of the starch-agar. In this set-up you could include a plate containing boiled enzyme.

Plates 1 and 2 contain diastase and barley grains respectively. When flooded with iodine, after 24 hours incubation, areas of clearing can be seen around the well containing diastase and the barley grains. There are no areas of clearing on Plate 3 where the cells of the barley have been killed by boiling, and the enzyme is no longer active. This can later be related to an understanding of denaturation of enzymes by high temperatures. >>

Figure 3 - 1) Barley mush. 2) Germinating barley seeds. 3) Soaked and boiled barley seeds. 4) Distilled water.

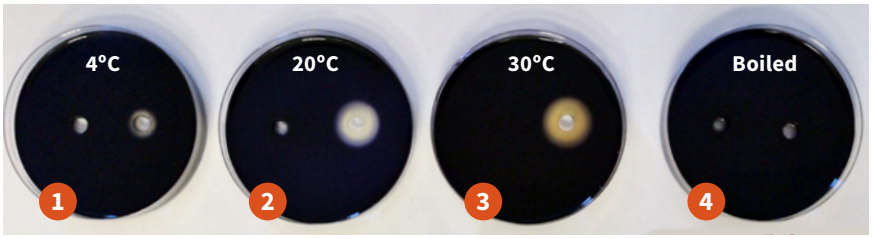


Figure 4 - 1) Fridge 4°C. 2) Room temperature 20°C. 3) Oven 30°C. 4) The 4th plate, containing water and boiled enzyme solution, is set up and left at room temperature.

The set-up in Figure 3 includes 'barley mush' created by grinding up several soaked barley seeds in distilled water and filtering the 'mush'. This might form the context for learners investigating the use of barley in the brewing industry and the role of 'malting' barley.

Activity 2 - The effect of temperature on the activity of diastase

Starch-agar plates each containing enzyme solution in the right hand well and distilled water, as a control, in the left hand well are set up and left for 24 hours at various temperatures, then flooded with iodine solution as illustrated in Figure 4.

The advantage of using this method to investigate enzyme activity is that, once the plates have been flooded with iodine solution, they can be rinsed and set out on a white surface in order starting with the one stored at the lowest temperature. Learners can easily see and compare the size of the clear zones. This provides an immediate and visual illustration of the relationship between enzyme activity and temperature. The effect of very low, or very high, temperature is evident. The fact that there is an 'optimum' temperature for the activity of an enzyme and that enzymes are denatured above a certain temperature can be introduced.

Setting the plates up as illustrated above also gives scope for discussion of experimental design. The use of controls, dependent and independent variables, method of measuring and recording results, and drawing conclusions can be discussed.

The appearance of plates after storage for 24 hours at different temperatures, followed by flooding with iodine solution can be recorded on diagrams, or by using digital/phone cameras, to provide a visual record of the results.

Quantitative data can be gathered by measuring the diameter of the clear zone at each temperature. Diameter of clear zone (mm) can be graphed against temperature (0°C) and used to draw conclusions about the effect of temperature on enzyme activity.

Activity 3 - The effect of pH on the activity of diastase

Diastase solution in a range of buffer solutions is set up in starch agar wells and stored for 24 hours at room temperature.

The enzyme at each pH will produce areas of clearing of different size. The appearance of the plate on flooding with iodine solution after storage at room temperature for 24 hours, allows pupils to conclude that enzyme activity is influenced by pH of the surrounding solution (Figure 5).

Protocols, a Teacher's Guide and a Technical Guide for the activities described here can be found on the SSERC website [3].

The protocols described here are based on activities described in *The Science of Life*, Strathclyde Biology Group, 1970. <<

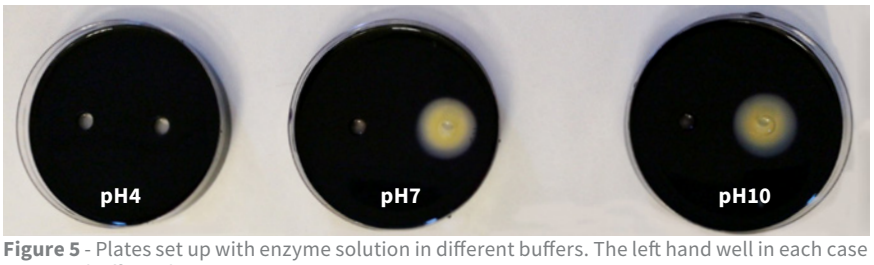


Figure 5 - Plates set up with enzyme solution in different buffers. The left hand well in each case contains buffer only.

References

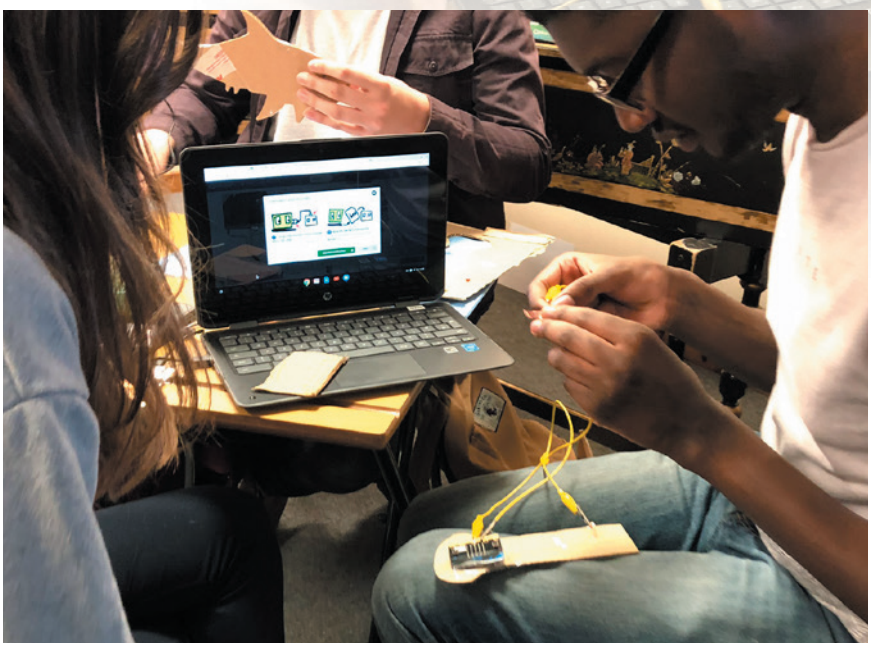
[1] National 4 Biology, https://www.sqa.org.uk/files_ccc/CfE_CourseUnitSupportNotes_N4_Sciences_Biology.pdf.
Sciences Experiences and Outcomes, https://education.gov.scot/Documents/sciences-eo.pdf.

[2] http://www.ncbe.reading.ac.uk/MATERIALS/PDF/NCBEpricelist.pdf.

[3] https://www.sserc.org.uk/subject-areas/biology/biology-national-4/properties-of-enzymes-and-use-in-industries2/.

Digital skills at SSERC

We are delighted to report that, with support from the government, we are able to deliver digital skills training across both primary and secondary sectors. A new Digital Skills Education Officer is in post and with the support of the Digital Team in Education Scotland, we have been able to offer a range of digital skills courses.



The courses are:

- Enriching Opportunities across the BGE - Early and First.
- Supporting Literacy and Language using Digital.
- Computing Science - Building and Testing Computing Solutions using Block Based Coding.
- Laying the foundations of Computing Science - Early and First.
- Computing Science: Enriching Opportunities across the BGE (3rd and 4th Level).
- Discovering Micro:Bits across the BGE.
- Reaching all learners using Digital tools.
- Supporting Learning using Rich Media.

In addition, we have been delivering external professional learning sessions in partnership with, and for, Education Scotland, Universities and Local Authorities.

During 2019/2020 we plan to increase the number and variety of courses and programmes offered in this important area of the curriculum.

Here is a link to our session catalogue for 2019/2020: https://sway.office.com/pL26C8sZQCGHlhNF?ref=Link. <<

"I loved the mix of information transmission, hands on playing and exploring and sharing of ideas and good practice. Being pointed in a direction for books and apps that are of high quality is invaluable when there is so much choice available. It's great to have time to give things a go so you can really imagine how it might work in your setting. I have also come away with nice videos, quotes and ideas to share with my staff to inspire them!"
Enriching Opportunities in Computer Science, Early and First Level

SSERC professional learning courses

Our professional development courses range from twilight events, day-courses through to residential meetings lasting up to 6 days in total. Our curriculum coverage spans both primary and secondary sectors and we offer events for teachers as part of their career long professional learning, newly qualified teachers and technicians. Many of our events receive funding from the ENTHUSE Bursary scheme or the Scottish Government.

Courses available for online booking include:

COURSE NAME	RESIDENTIAL?	DATES	CLOSING DATE	SECTOR
Working with Radioactive Sources	No	20 August 2019	20 June 2019	Secondary
PAT Testing	No	22-23 August 2019	20 June 2019	Secondary (Technicians)
Introductory Chemistry	No	22-23 August 2019	20 June 2019	Secondary (Technicians)
Intermediate Physics	No	27-28 August 2019	20 June 2019	Secondary (Technicians)
STEM CLPL for Early Level	No	30 August 2019	23 August 2019	Primary
Safe Use of Workshop Machinery	No	3-4 September 2019	21 August 2019	Secondary (Technicians)
Physics (Blended Professional Learning)	No No No No No Yes	4 September 2019 11 September 2019 18 September 2019 25 September 2019 1 October 2019 13-14 December 2019	28 June 2019	Secondary (Physics)
Laboratory Science National 5 (Lab Skills)	Yes	11-13 September 2019	21 June 2019	Secondary (Science)
Maintenance of Fixed Workshop Machinery and Tools	No	18-20 September	22 August 2019	Secondary (Technicians)
Chemistry Residential	Yes	19-21 September 2019 13-14 March 2020	23 August 2019	Secondary (Chemistry)
Assignments for Environmental Science	No	27 September 2019	3 September 2019	Secondary (Environmental Science)
SSERC_Meet Light: Shades & Shadows	No	26 September 2019	30 August 2019	Primary
SSERC_Meet: Fun with Forensics	No	2 October 2019	6 September 2019	Primary
Safe Use of Workshop Machinery (Refresher)	No	2 October 2019	31 August 2019	Secondary (Technicians)
Biology Residential	Yes	3-5 October 2019 & 28-29 February 2020	6 September 2019	Secondary (Biology)
Engineering Bench Skills	Yes	24-25 October 2019	27 September 2019	Secondary (Technology)
Advanced Higher Biology Day	No	26 October 2019	28 September 2019	Secondary (Biology)
Creativity	Yes	28-29 October 2019	27 September 2019	Primary & Secondary
Safe Use of Workshop Machinery	No	30-31 October 2019	2 September 2019	Secondary (Technicians)

Please check our website pages at **https://www.sserc.org.uk/professional-learning/calendar/** for the most up-to-date details on our career long professional learning calendar.

The Young STEM Leader (YSL) Programme:
Inspiring and developing young people through STEM

A new Scottish programme which will give children and young people the chance to develop their personal skills through Science, Technology, Engineering and Mathematics (STEM) is being piloted this month (June).

Aiming to spark greater interest and participation in STEM, the YSL programme will give children and young people the opportunity to lead, inspire and mentor their peers through the creation and delivery of STEM activities within schools, Early Years Centres, community groups and youth initiatives.

Young STEM Leaders (YSLs) can do anything from running a coding club at lunch-time with friends to helping a classmate struggling with their coursework to dreaming up and leading a unique STEM activity or event in their community. The programme encompasses a wide definition of STEM, including gaming, music, digital, design and the environment.

For younger pupils, the YSL programme offers a great chance to unleash their creativity and get hands-on either in the classroom or with a community group. For teens, it represents an excellent way to develop personal skills that will help them stand out from the crowd with employers and university/college admissions.

As well as helping the Young STEM Leader (YSL) to develop important 'soft' skills such as leadership, active listening, mentoring, organising and creativity, it is hoped that the programme will motivate YSLs to continue with their STEM studies and embark on a career in STEM.

Levels of the YSL Programme

The Young STEM Leader (YSL) programme will be non-formally accredited at Curricular Levels 2, 3 and 4, underpinned by a framework that identifies the skills, knowledge and behaviours expected of a Young STEM Leader at each level.

SCQF Levels 4, 5 and 6 will be formally accredited and certificated, underpinned by outcomes and performance criteria for each level.

Every YSL will receive digital and face-to-face training on the skills, knowledge and behaviours required to complete each level.

The Scottish Government's Strategy for STEM Education and Training (2017) [1] has committed to 'establish a new Young STEM Leaders programme to stimulate and strengthen the development of peer mentoring and inspiration in STEM for children and young people by children and young people.'

The YSL programme is being funded by the Scottish Government led by SSERC and a range of partners, including the Scottish Science Centres, Scottish STEM Ambassador Hubs, Science Festivals, YouthLink Scotland, Young Scot, Children in Scotland, Education Scotland and the Scottish Mentoring Network.

Graeme Rough, YSL project manager, said: 'This is a fantastic opportunity for children and young people to discover, create, inspire and lead their peers, in the process developing a range of highly-desirable and transferable personal skills. As well as improving their own STEM skills and knowledge, those working with the YSLs will also be inspired by these positive young role models.'

The YSL programme will be rolled out across Scotland by 2020. More information on the YSL programme is available at www.sserc.scot or from the project team at ysl@sserc.scot. <<

Reference

[1] https://www.gov.scot/publications/science-technology-engineering-mathematics-education-training-strategy-scotland/.

Out-of-balance Wheatstone Bridge

This is another article that might help you guide your students towards a successful Higher Investigation. The Wheatstone Bridge is not mentioned in the Higher Physics Course Specification. The potential divider is included, and the Wheatstone Bridge can be thought of as an application using two potential dividers. Investigating the voltage across the bridge when it is out of balance is straightforward and, if the correct setup is used, gives good results.

Theory – Balanced Wheatstone Bridge

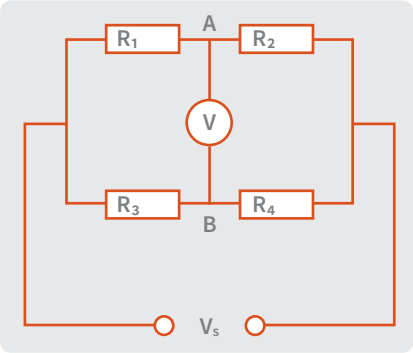


Figure 1 – Wheatstone Bridge circuit.

A Wheatstone Bridge (Figure 1) consists of two potential dividers. The voltages V_1 and V_3 across resistors R_1 and R_3 can be calculated as follows:

$$V_1 = \frac{R_1}{R_1 + R_2} V_s$$

$$V_3 = \frac{R_3}{R_3 + R_4} V_s$$

V_s is the supply voltage. When the voltmeter reads zero, $V_1 = V_3$. There is no potential difference V across the "bridge" AB and the bridge is said to be "balanced". If we equate the above expressions for V_1 and V_3, we can show that, when there is no potential difference across AB,

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

A Wheatstone Bridge can be used to measure resistance, though this is no longer common practice. Suppose the resistances of R_3 and R_4 are known. R_1 is the unknown resistance and R_2 is a calibrated variable resistance.

R_2 is adjusted until V reads zero. The value of R_2 is noted. R_1 can then be found from:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Theory – Out-of-balance Wheatstone Bridge

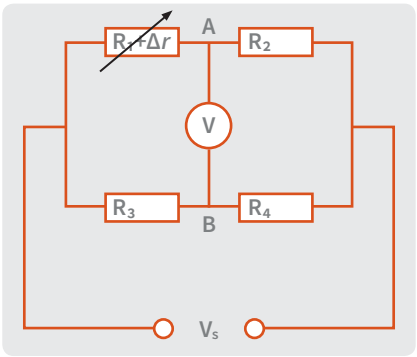


Figure 2 - Unbalanced Wheatstone Bridge.

If the bridge is initially balanced (V = 0 V) and R_1 has its resistance increased or decreased by Δr (Figure 2), the bridge will no longer be balanced. There will be a potential difference across the bridge and V will no longer read zero volts.

It can be shown that if Δr is small compared to R_1,

V is proportional to Δr.

Take the special case where R_3 and R_4 are equal and, when the bridge is balanced, R_1 and R_2 are also equal. You can have fun proving that, in this specific case, if R_1 changed by a resistance of Δr ohms:

$$V = \frac{\Delta r}{4R_1 + 2\Delta r} V_s$$

Note that Δr can be positive or negative. There is no need for anyone to know this formula. It is included to show that, in this case at least, V is proportional to Δr, provided that Δr is much smaller than R_1.

We address the question, "How much smaller is much smaller?" shortly. >>

Figure 3 - calibrated variable resistor.

Carrying out the investigation

We used the following apparatus:

- 3x 330 Ω resistors, 10% tolerance
- Calibrated variable resistor, range 0–9999 Ω in steps of 1 Ω. Such devices typically claim to be accurate to within 1%. See Figure 3.
- 5 V dc power supply - batteries could be used. The voltage is not critical, but if too small, the out-of-balance voltage will also be small.
- Voltmeter capable of reading to 0.1 mV

The Wheatstone Bridge was set up as shown previously. The variable resistor, set to 330 Ω, was placed in the R_1 position. This should have resulted in a balanced bridge, i.e. a zero reading on the voltmeter, but it did not, and adjusting the variable resistor could not restore balance. Its 1 Ω increments were too large. If this happens, there are two possible solutions, one of which might work and another which definitely will.

You may be able to obtain balance by swapping the 330 Ω resistors around. They are made with a tolerance of 10%, i.e. they could be as much as 33 Ω above or below the nominal 330 Ω. If this does not work, one of the fixed resistors will have to be replaced by a rheostat that can be set at least as high as the given resistance of the fixed resistors. This is adjusted until the bridge is balanced. The value it is set to does not matter and it is not adjusted throughout the investigation.

It is, of course, not essential to use 330 Ω resistors. The value is "ballpark".

With the bridge balanced, R_1 was adjusted in steps of 1 Ω. We measured V with R_1 ranging from 320 Ω to 340 Ω, giving a range for Δr of -10 Ω to 10 Ω.

Results are shown above in Figure 4.

Note that when we did the investigation, the results were not symmetrical. By this we mean that the magnitude of the value of V for Δr = -10 Ω was not exactly the same as that for Δr = +10 Ω, for example. This was not due to poor initial balancing - when we modelled an out-of-balance Wheatstone Bridge using a spreadsheet, we got the same result. However, you have to analyse the results quite closely to see a deviation from direct proportionality.

This proportionality, or near-proportionality, only holds if Δr is much smaller than R_1. This is why we chose the values of fixed resistors to be around a few hundred ohms and incremented in 1 Ω steps . The graph in Figure 5 shows what happens if you increase Δr by increments of 10 Ω.

Note that only positive increments of Δr were used in this stage. We see a clear departure from linearity at larger values of Δr.

If you are thinking that using larger values for the fixed resistances but continuing to increment Δr in steps of 1 Ω would give even better linearity, you would be correct. However, the trade-off is that V would be smaller, perhaps too small to measure accurately. The ratio Δr:R_1 of 1:330 appears to be a good compromise.

Why bother?

Out-of-balance Wheatstone Bridges are very common in sensing and monitoring circuits. For example, one of the resistors could be a thermistor. Over a certain range of temperatures, V the out-of-balance voltage will be proportional to change in temperature.

Note on use of this article

When preparing these articles, we choose graph markers and gridline spacings for their clarity. We are aware that students using such markers and spacings might well be penalised in assignment write-ups for doing so. This material is not intended for student use though you are free to edit it to create something that could be useful to them. It is not intended as a second source of data either. <<

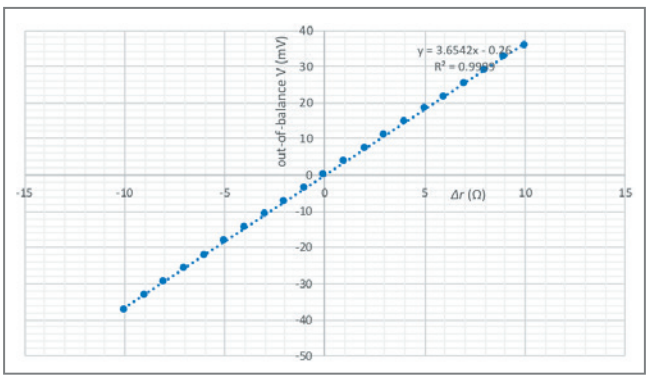


Figure 4 - Out-of-balance V versus Δr.

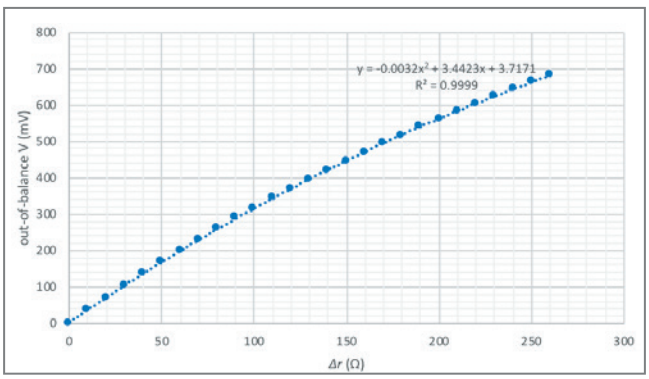


Figure 5 - Out-of-balance V versus Δr with larger Δr.

SSERC in Partnership with The Scottish Childminding Association

At SSERC we pride ourselves on providing excellent STEM (Science, Technology, Engineering and Mathematics) focused Career Long Professional Learning (CLPL) opportunities for educators across Scotland.

From the early years all the way through to college we support teachers, classroom assistants and technicians to keep up-to-date and improve their knowledge and skills. Now we are delighted to be extending our work to provide childminders in Scotland with STEM training and resources in partnership with the Scottish Childminding Association (SCMA).

The 2017 STEM Education and Training Strategy for Scotland [1] recognises the importance of early intervention, stating "The early years are crucial in providing a foundation in STEM skills and in inspiring and igniting children's enthusiasm." With the 2020 deadline fast approaching for the early year's expansion in Scotland, which will see all children over the age of three eligible for 1140 free hours per year of early education and childcare, childminders are being recognised more than ever as an integral part of this provision [2]. Maree Todd the MSP for Childcare and Early Years reiterated this recently when she announced the provision for more training and development for childminders.

Part of this provision comes in the form of STEM learning and development. Head of Childminding Services in Scotland Janine Ryan worked with SSERC to apply for funding under Education Scotland's Enhancing Professional Learning in STEM grant scheme. With funding approved, work is now well underway between SSERC and SCMA to deliver on phase one of the proposal which includes providing both e-learning modules and face-to-face training for childminders as well as a bank of resources.

It is important to remember that parents don't choose childminders to provide a formal education but to allow their children to enjoy the care and play opportunities which are unique to a home setting. Play-led learning is gaining an increased recognition as the best way for young children to learn, after all, even Einstein said, "play is the highest form of research". This means that any training needs to link to the Curriculum for Excellence and suit a play-based environment with supporting resources being readily available in any home or park, so out with the magnets and motors and in with the play dough and pinecones.

Training modules filled with childminder friendly ideas and activities and the science behind them have been produced and will be available online at www.childminding.org for members of SCMA by June 2019. The modules include; an Introduction to STEM, Senses, Science Inquiry and STEM Outdoors. We will also be welcoming childminders from across Scotland to SSERC for face-to-face training on 29 June 2019.

We look forward to continuing to work with the SCMA to support the amazing work that childminders across Scotland do. <<

scma Scottish Childminding Association
committed to quality childcare

References

[1] Gov.scot. (2017). Science, Technology, Engineering and Mathematics: education and training strategy - gov.scot, available at https://www.gov.scot/publications/science-technology-engineering-mathematics-education-training-strategy-scotland/ (accessed 12th May 2019).

[2] Consult.gov.scot. (2016), available at https://consult.gov.scot/creating-positive-futures/expansion-of-early-learning-and-childcare/user_uploads/451371_blueprint-2020.pdf-1 (accessed 12th May 2019).

The wonderful thing about TIG rods

...is that some types can be used as low-risk radioactive sources for certain experiments and demonstrations. Here we look at what TIG rods are, how to handle them safely and what uses they can be put to.

Figure 1 - thoriated TIG welding rod, as supplied with the Lascells cloud chamber.

What are TIG rods?

Tungsten Inert Gas (TIG) welding is a form of arc welding. To improve the quality of weld and to make the welding process easier, thorium is sometimes added to the electrode when it is manufactured. A typical thoriated electrode will contain around 2% thorium by mass. The TIG electrode is consumed in the welding process but the material does not form part of the weld. Nevertheless, these electrodes are usually referred to as TIG welding rods.

Thorium is radioactive. A thoriated TIG welding rod will emit alpha, beta and gamma radiation from the thorium and its decay products. The activity of a rod will be around 3 to 7 kBq. Sealed radioactive sources used in schools typically have activities of 70-370 kBq and are designed to emit predominantly one form of radiation.

How do I use them safely (and legally)?

Thoriated TIG welding rods are not subject to much of the legislation that covers radioactive sources in schools. Care must still be taken when using them. Here is some guidance. Please note that were you to weld with a thoriated TIG rod, the control measures would be very different.

- Do not saw, grind or file a thoriated TIG welding rod. These actions will produce small particles containing thorium. The thorium could be inhaled, ingested or could enter the body through a wound.

- Keep the rods in your radioactivity store if you have one and add them to your inventory. If you don't have a radioactivity store, at least ensure they are labelled as "thoriated TIG rods". There is no need to use the ionising radiation warning symbol.

Rods can be handled without protective equipment. The dose rate to a part of the body touching a TIG rod is about four times that of background radiation and it drops rapidly with distance. Clothing will shield you from the alpha radiation. You could walk around with a thoriated TIG welding rod in your pocket for hundreds of hours in a year before receiving the 10 microSievert dose considered to be negligible by the International Commission on Radiological Protection.

What can they be used for?

The electronically-cooled Lascells cloud chamber that SSERC put into each local authority in 2015 [1] uses a thoriated TIG welding rod as a source. As it emits heavily-ionising alpha radiation, it is ideal for producing strongly-visible tracks. If you have an older cloud chamber that came with a radium source, that source should have been disposed of by now. A thoriated TIG welding rod makes an excellent substitute.

If you are running the *National 5 Skills for Work – Laboratory Science* course, you will know that students are required to measure radiation. They cannot use the majority of school sources if there are any under-sixteens in the room. SSERC has suggested using potassium compounds or carrying out the radon balloon experiment. Using thoriated TIG rods is another age-unrestricted activity. With the rod a few mm from the end of our Geiger-Müller tube, we measured a count roughly four times that of background alone.

Finally, it is good to be able to show that some objects happen to be radioactive, not because they require to be but due to the presence of a radioactive substance that has some other useful property. Low sodium salt is one example. It contains potassium chloride, which is mildly radioactive. The radioactivity confers no health benefits but neither does it pose a risk sufficiently large to negate the positive effects of reducing sodium in one's diet by using low salt.

Thorium-free thoriated TIG rods

Cerium oxide or lanthanum can be used as substitutes for thorium in TIG rods. We know of some schools who have bought welding rods marketed as "thoriated", only to find that there is no detectable radiation above background level from the rods. We suggest buying "over the counter" where possible. <<

Reference

[1] https://www.sserc.org.uk/wp-content/uploads/2015/05/SSERC251_p2.pdf (accessed May 2019).

Welding in schools

The Health and Safety Executive has recently announced that it has raised the control standards for welding fumes to now include the welding of mild steel.

New scientific evidence has been published that indicates that that exposure to mild steel welding fume can cause lung cancer and possibly kidney cancer in humans. Based on this scientific evidence the HSE have strengthened their "enforcement expectation" on all types of welding fume. It is now no longer deemed adequate to weld mild steel in just a well-ventilated area as it does not achieve the necessary level of control.

So how does this relate to welding in the school craft room?

Well, as with all HSE regulations this "enforcement expectation" also applies to all educational establishments with immediate effect. All welding fume is now classed as carcinogenic. Regardless of welding duration, any welding done without suitable exposure control measures in place will not be acceptable.

Figure 2 - Portable style Extraction Unit.

Figure 1 - Welding booth showing movable extraction arm/hood.

So what control measures should be in place?

Any welding tasks undertaken indoors will require suitable engineering controls to be employed such as Local Exhaust Ventilation (LEV). A typical school setup like figure one would be expected. It should be noted that with this type of extraction (a flexible arm and capture hood) it must be positioned as close as practically possible to the weld area in order to provide effective extraction.

This type of LEV system must be suitably maintained and is subject to a thorough examination and test every 14 months.

If the LEV system employed alone does not adequately control exposure risk, it must be supplemented with suitable respiratory protective equipment (RPE) such as an FFP2 classed mask as a minimum or better still and FFP3 mask. Any welding done outdoors will require the use of RPE.

Other types of welding extraction available include those similar to the one shown in Figure 2. This type of "portable" extraction system uses series of internal filters to capture harmful fumes before recirculating the air back into the room.

It should be highlighted that Risk Assessments should reflect this change and the necessary control measures be taken. The HSE have advised that they will be updating their guidance on welding mild steel as soon as possible. SSERC will also be updating the model welding risk assessment. <<

Sodium in water incident

An incident has come to our attention that merits wider circulation.

One method of carrying out the alkali metal in water reaction is to place a perspex sheet flat on the top of the basin of water, rather than using safety screens set up vertically around the trough.

In general, there seems to be no problem with this method. However, recently a teacher, having carried out the experiment once did it again shortly after, just moving the cover enough to allow the fresh piece of sodium to be dropped in.

The spark as the sodium came in contact with the water was enough to ignite the hydrogen air mixture that had been produced by the previous batch and a jet of flame shot out of the narrow opening, burning the teacher. Fortunately, not causing major injury.

The lesson to be learned here is that if you are using this method, remove the covering completely for a few seconds before a repeat experiment to allow the hydrogen to disperse. <<

Everybody needs good NEBOSH

SSERC's chemistry specialist Chris Lloyd has become the latest member of the organisation to gain the NEBOSH National Diploma in Occupational Health and Safety. This is a major achievement as the qualification involves extensive studying, exams and the submission of a lengthy dissertation.

The Diploma is evidence of a deep understanding of Occupational Health and Safety. Having staff who hold this qualification is of great benefit to SSERC and to our members. It is the gateway to Chris attaining Chartered Membership of IoSH, another certification that is highly regarded by those in the health and safety community. <<

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