Alice Hamilton – safety, hazards and risk

Teachers’ notes

Objectives

- To show how scientific work can be affected by the contexts in which it takes place.
- To learn about the powers and limitations of science in addressing industrial, social and environmental questions.
- To show the importance of carefully planning an investigation.
- To understand the importance of controlling hazards and reducing risks to maintain a safe working environment.

Outline

The introductory material about Alice Hamilton illustrates that scientific evidence can lead to changes in legislation and improved working conditions. The resource is presented as three case studies, followed by suggestions and guidance for carrying out project work.

- Case study A The typhoid problem at the start of the century
- Case study B Alice Hamilton investigates industrial lead poisoning
- Case study C Alice Hamilton investigates carbon monoxide poisoning
- Project work.

Teaching topics

These activities are suitable for 14–16 year olds and could be included when teaching about useful products from metal ores and rocks or about carbon monoxide and different types of reactions.

Background information

The life and work of Alice Hamilton is used to illustrate the importance of safety when working with and dealing with chemicals. At the turn of the century, the Europeans were more aware of industrial poisoning than the Americans. In the USA there was no legal health protection at work or compensation for ‘poisoned’ industrial workers. The situation in Britain was much better. By 1928 the Home Office was making a new set of rules for the control of lead poisoning in storage battery plants. Unlike in the United States of America, the trade unions’ and factory experts’ representatives in Britain had equal rights and so it was easier for legislation to be made that looked after the interests of the factory workers to be written and subsequently enforced. Alice Hamilton was born in and lived in the United States of America. She used her medical background and scientific training to fight the American authorities. Her many investigations led to safer working conditions for thousands of people and, in many cases, legislation concerning aspects of public health. Her impact on the industrial society was enormous. Her reputation went before her to the extent that some managers tried to cover up the poor working conditions and told sick workers to stay at
home during her visits. Needless to say, they were found out because Alice made it her business to talk to the ordinary people in the towns and villages.

Alice Hamilton carried out many interesting studies in her lifetime, covering a wide range of chemicals. This section focuses on the typhoid problem, lead poisoning and carbon monoxide poisoning, as they each illustrate different aspects of scientific enquiry, and will easily slot into a teaching scheme.

**Health – long term effects**

The project work approach could be adapted to other people and other safety problems eg Marie Curie and radiochemistry, comparing working conditions now and then. A good resource and starting point is *100 years of Radium, Marie Curie and the History of Radiochemistry*, Hatfield: The Association for Science Education and The British Society for the History of Science, 1999 (ISBN 0 86357 299 5).

**Source of information**

The autobiography of Alice Hamilton provides details of many of her other investigations.


**Teaching tips**

Alice Hamilton investigates public health

This could be introduced by explaining that, when Alice Hamilton lived, not much was known about the hazardous nature of many chemicals or the risks they posed. The materials worked with were slowly poisoning many of the factory workers. Over the years Alice Hamilton played a prominent role in bringing these concerns to the attention of the government and industry.

The resource can be used to emphasise the importance of observing safety rules today, such as no food or drink to be taken into the laboratory and washing hands after handling chemicals etc. This could then lead into a discussion on the importance of reducing the risks we face in the workplace, and an introduction to risk assessment.

**Case study A**

This can be used as a model for carrying out an investigation or used to focus investigational skills such as observation and testing out different theories.

**Case study B**

This could be used prior to carrying out a smelting experiment in class or as a follow up piece of work.

Refer also to *Classic Chemistry Experiments*, Royal Society of Chemistry: London, 2000, experiment number 35.

**Case study C**

This activity helps students to become familiar with the information contained on the CLEAPSS students safety sheets.
Project work

Suggested project questions are found at the end of each case study. When carrying out project work, the student’s interest could be captured by focusing on a current or local issue.

Suggestions and guidance for carrying out project work

This is an example of how a project could follow on from Case Study C on carbon monoxide poisoning. This approach could be applied to almost any topical issue.

Introduce the project as a real problem, needing real solutions and answers.

Newspaper headlines You may wish to use a couple of headlines to stimulate interest and discussion at the start of the project. These articles could be transferred on to an OHT slide.

Context The students could be acting as reporters for newspapers, magazines, local councils etc. As a reporter it is their job to investigate the problem, looking for evidence to support or reject an initial claim, and suggesting ways to try and minimize the problem and public fears. It is important to emphasise and keep the project focused on science. This can be achieved by using prompt questions at the start, or by stating expected outcomes. We all know how easy it is to be sidetracked and go off at a tangent. Some type of final presentation either written or in the form of a poster or as an oral presentation or debate should be the final outcome. For further details see Teaching students to communicate ideas in science, p. ix.

The material is suitable for either individual or group work, depending on time constraints and student ability. If working in groups, the group should be no larger than 4, with each group member having a specific task to carry out, (eg each group member taking a different point) so that real team work is achieved and not all the work is done by one or two dominant characters.

Resources

- CLEAPSS or SSERC student safety sheets or HAZcards
- Encyclopaedia
- Science dictionary
- Internet access
- Overhead projector (OHP)
- Student worksheets
  - Alice Hamilton investigates public health
  - Carbon monoxide: introducing the problem
  - Carbon monoxide project work
  - A detector calls three page reprint article from Chemistry in Britain. (Reproduced with kind permission from Chemistry in Britain R. Kingston Chemistry in Britain, 1999, 35(4) 44–46.)

Timing

Case studies
Each study will take about 60 minutes
Project work
As with any type of project work the timing is very important and tight deadlines must be set and enforced. For example, students should be told in advance when the resource room/ICT room is available to use during lesson time, when their initial research should be completed by, when poster making materials etc will be available, and of course a completion deadline. Experience has shown that if deadlines are not enforced the project can drag on for a very long time, because in this type of work there is always room for improvement as new ideas come along later.

At the onset of the project it is important to decide how much lesson time and homework time you wish to spend on the project, and pass this information on to the class.

Opportunities for using ICT
The project work approach presents opportunities for using:
- The Internet
- CD-ROMs
- Word processing
- Software packages suitable for presenting work.

Opportunities for key skills
- Communication
- Application of number
- Working together.

Answers

Alice Hamilton investigates public health
1. 101
2. She spent her life working with dangerous and poisonous chemicals. She also lived with people who often contracted fatal contagious diseases.
3. She wanted to help the poor people who were living and working in poor conditions. She believed that everyone had the right to be safe at work and should not have to suffer because employers did not want to invest in cleaning up the work place.
4. Most of these chemicals have been superseded by safer chemicals today. However, you will still find that some of the chemicals are in use today in more controlled applications.
5. People are more aware of safety today and employees in the workplace are protected by the law. There are many documented studies surveys on the safety and use of chemicals today. When new chemicals are produced, the safety of that material is studied.

Case Study A
1. Flies were feeding on typhoid infected waste from overflowing privies and household waste. The flies landed on food and milk, which was consumed by the people who were now infected.
2. She collected flies from the privies and kitchens. She dropped them into broth and incubated the tubes for different amounts of time.

3. The results showed that the typhoid bacteria were present, thus supporting Hamilton’s theory.

4. To cover up food and drink. To wash your hands before cooking, eating or drinking and after going to the toilet. To wash down the kitchen surfaces before preparing food and to clear up afterwards.

5. At the local pumping station on West Harrison Street, a break occurred which resulted in an escape of sewage into the water pipes. The public drank the infected water for three days.

6. When the results from Hamilton’s theory supported her theory she thought that she had found the cause of the epidemic and so stopped her investigation.

Case Study B
1. Lead metal – low hazard. Lead oxides are toxic. Harmful if swallowed or the dust is breathed in. The compound builds up over a long period of time. It may harm an unborn child.

2. To avoid breathing in dust or fumes, wear a facemask. Make sure that protective clothing is worn while working with the compounds and that the clothing is removed before going home. Always wash your hands after handling lead compounds.

3. Hamilton could have made the following recommendations to:
   a) the enamel industry – to clean up the lead dust, to provide a common room for the employees to eat their lunch, to ensure that the employee changed their clothes and washed their hands as they left the factory floor. A clean room being provided for changing and washing.
   b) the smelting industry – as for the enamel industry and to regularly service smelting machinery and improve the ventilation so that the lead fumes could escape.

4. The painters were proud people and wanted their work to be of the highest quality. The lead and turpentine paints gave better results than other paints. If they used cheap paints, with poor results then perhaps no one would employ them. They were prepared to risk their health but not their reputation.

Case Study C
1. CO

2. \( 2C + O_2 \rightarrow 2CO \)

3. Toxic and flammable

4. CO is a colourless, odourless, tasteless and non-irritant gas and there were no chemical tests available.

5. Poor ventilation when using gas fires.

6. Good ventilation is needed.
Alice Hamilton
investigates public health

Alice Hamilton (1869–1970)
(Reproduced with permission from Bentley Historical Library, University of Michigan.)

Alice Hamilton went to a girls’ boarding school where very little science was taught. Her ambition was to be a doctor, so she had to learn chemistry and physics in the summer holidays. She was successful and went to Michigan Medical School.

In 1897 Alice decided to live at Hull House settlement home, in Chicago. Settlement homes offered help to poor people such as immigrants from run-down inner cities. She was concerned about the dirty living conditions and working conditions in the factories. She investigated typhoid fever and tuberculosis.

She spent thirty years of her life investigating factory working conditions and studied the effect of dangerous chemicals on humans. As a result of her work, in 1937 new laws were passed in the USA giving compensation for industrial diseases.

Alice Hamilton’s investigations into hazardous materials

She:

- Studied white lead and lead oxide substances that were commonly used as pigments in the paint industry and recommended safer working conditions.
- Investigated the poisonous effects on workers of manufacturing explosives.
- Studied aniline dyes, carbon monoxide, mercury, tetraethyl lead, radium (in wristwatch dials), benzene, the chemicals in storage batteries, carbon disulfide and hydrogen sulfide (created in the manufacture of viscose rayon).

Questions

1. How old was Alice Hamilton when she died?
2. Why might you be surprised by her age?
3. What do you think motivated Alice Hamilton to carry out her investigations into hazardous materials?
4. Try and find out which of the chemicals she studied are in use today? Hint: You could look up the chemical names on a science CD-ROM or use an encyclopaedia.
5. Does this tell us anything about safety today?
Case Study A The typhoid problem at the turn of the century

Typhoid is a bacterial disease that causes a high fever and attacks the intestines. Bacteria live in warm, wet conditions where there is a good food supply.

Background information

- Drinking water – was taken straight from the lake with no chlorine treatment.
- Precaution taken against pollution – daily water samples were taken to make cultures. The next day the results were published, advising whether or not to boil the water.
- Assumption – housewives would look at the results and act upon the advice.

Alice Hamilton Investigates the 1902 Typhoid Epidemic at Hull House in Chicago

Facts:

- Hull house was at the centre of the epidemic.
- Hull house used the same main water and milk supply as less affected areas.

Deduction:

- It must be a local problem.

Investigation

- Observations – around the local streets showed that some outside privies (toilets) were overflowing into the backyards and streets, mixing with the rainwater. The whole area was very dirty, the plumbing was out of order and there were flies everywhere.
- Knowledge – during the Spanish-American war in 1898, studies had shown that typhoid was spread by house flies.
- Hypothesis – the flies were feeding on typhoid infected waste and then landing on the food and milk.
- Experiment – Alice collected flies from privies and kitchens. She dropped them into broth and incubated the tubes for different amounts of time. The results showed ‘typhoid bacteria’.
- Conclusion – dirty living conditions was the cause of the typhoid epidemic.
- Outcome – a public enquiry resulted in a complete reorganization of the Public Health System. There were regular tenant house inspections.

Board of Health kept the real cause to themselves

At the local pumping station on West Harrison Street, a break had occurred which resulted in an escape of sewage into the water pipes and for three days the neighborhood drank the water, before the leak was discovered and stopped.

Questions

1. What did Alice Hamilton believe was the cause of the 1902 typhoid epidemic?
2. How did she test out her theory?
3. Did the results support or undermine her theory?
4. As a safety officer what advice would you give to the local people to try and avoid typhoid in the future?
5. What was the real reason for the 1902 typhoid epidemic?
6. Why do you think Alice Hamilton did not test the local water supply and find the real cause sooner?

Project or extension work

Find out about the measures that are taken today to ensure that typhoid epidemics are no longer common in this country.

Getting started – carry out an Internet search on typhoid.
Case Study B Alice Hamilton investigates industrial lead poisoning

The enamel industry – 1912

When the enamel workers were on strike in 1912, Alice Hamilton took the opportunity to examine them. She was looking for the ‘lead line’, which is a deposit of black lead sulfide in the cells of the lining of the mouth. It is usually clearest on the gum along the margin of the front teeth. The line is formed when lead reacts with protein in food that is being eaten and indicates lead poisoning. The results were alarming, and showed 54 out of 148 workers had ‘lead lines’. Examining hospital and doctor’s records confirmed the extent of severe lead poisoning.

Walking around the factories Alice Hamilton observed a lot of lead dust and men eating their sandwiches in the same rooms without washing their hands or changing out of their work clothes.

Lead smelting

A similar study revealed lead poisoning was just as widespread in the smelting industry. The main dangers came from:

- **Dust** when the ore was ground, when the charge was fed into the furnaces and when the flues were cleaned out.
- **Lead fumes** that escaped from the furnace.

Once again the workplace was very dusty and hands were not washed when food was eaten. Machinery was simple and not kept in good order, so lead fumes escaped into the very hot rooms which were not well ventilated.

Painting

Around 1913, there were two hazards associated with the painter’s trade; lead and turpentine. The risks they posed were well known. However, the paint that gave the best results was lead and turpentine based. The newer cheaper paints were based on a leadless pigment and naphtha and was not liked. The painters preferred the lead based paint and were willing to take the risk of lead poisoning. They often complained about the headaches and nausea caused by turpentine fumes.

As Alice Hamilton investigated she was sure that once again the ‘unwashed hand theory’ would be supported. The investigation showed that the workplace was very dusty, especially when surfaces were being rubbed down and white and red lead were being mixed with oil. Hospital records confirmed a number of cases of lead poisoning amongst painters.

By the 1940s iron and titanium oxides replaced the lead oxides used in paints.

Questions

1. Using the appropriate student safety sheet, what is the main hazard posed by lead and lead oxide?

2. What precautions should be taken when working with lead compounds?

3. When Alice Hamilton wrote her report, what general recommendations do you think she made to:
   - a) the enamel industry?
   - b) the smelting industry?

4. Why do you think painters were willing to take the risk of using leaded paints when there were alternatives available?

Extension or project work

Find out more about the effects of lead poisoning and then decide whether you would you be willing to use a lead based paint every working day.
Use the information above and the student safety sheet or HAZcard on carbon monoxide to answer the questions.

Questions

1. What is the chemical formula for carbon monoxide?
2. Write an equation for the slow combustion of coal in a limited oxygen supply.
3. Which safety symbol(s) would you assign to carbon monoxide?
4. Why do you think it was difficult for Alice Hamilton to investigate carbon monoxide poisoning?
5. What is the main cause of carbon monoxide poisoning in the home today?
6. What precautions should be taken to avoid carbon monoxide poisoning today?

Extension or project work

**Carbon monoxide the silent killer** – Find out how carbon monoxide levels are detected and monitored today (at home and in industry.)
Find out how carbon monoxide slowly starves the brain of oxygen.
Carbon monoxide: introducing the problem

Carbon monoxide the silent killer – claims about 200 victims a year in the 1990s according to the Royal Society for the Prevention of Accidents (RoSPA).

02 February 1999, The Times, p.2
Home news – News in brief

Family die of fume poisoning

A family of four were found dead at their home yesterday from carbon monoxide poisoning. Neighbours of Jeffrey Cheetham, 37, his wife Beverley, 36, and their sons Christopher, 10, and Carl, 8, called police after noticing that curtains at the house in Brimington, Derbyshire, had been drawn since Sunday. After officers broke in, several were overcome by gas and had to be taken to hospital for tests.

14 March 1999, The Sunday Times Features – Education

How to be safe but sorry

By Jennie Brist

As for awareness: a university’s obsession with promoting personal safety advice hits you as soon as you arrive at your freshers’ fair. Bombarded with leaflets about the danger of drink, drugs, sex, meningitis and carbon monoxide poisoning.
# Carbon dioxide (CO₂) and monoxide (CO)

<table>
<thead>
<tr>
<th>Substance</th>
<th>Hazard</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide gas</td>
<td><img src="https://example.com/danger-icon" alt="DANGER" /></td>
<td>Can cause asphyxiation if proportion of carbon dioxide in the air becomes too high, e.g., as a result of the rapid evaporation of the solid in a confined space, or, in some African lakes, released from decaying organic matter. As it is denser than air, may build up in low areas, e.g., in caves. For a 15-minute exposure, concentration should not exceed 27,400 mg m⁻³. About 0.04% present in normal air as compared with about 0.03% 50 years ago. This increase is the result of burning fuels in motor vehicles, power stations, etc. This is in turn believed to be causing a very gradual rise in the temperature of the Earth (global warming) as a result of the greenhouse effect.</td>
</tr>
<tr>
<td>Carbon dioxide solid “dry ice”</td>
<td><img src="https://example.com/danger-icon" alt="DANGER" /></td>
<td>Causes frostbite (burns) – needs careful handling. If it evaporates rapidly in a closed vessel may cause explosion or, in a confined space, may cause asphyxiation as the air is forced out.</td>
</tr>
<tr>
<td>Carbon monoxide gas</td>
<td><img src="https://example.com/toxic-icon" alt="TOXIC" /> <img src="https://example.com/extremely-flammable-icon" alt="EXTREMELY FLAMMABLE" /></td>
<td>Toxic if breathed in, with the danger of serious damage to health by prolonged exposure. May cause harm to the unborn child. As little as 0.01% can cause headaches. The gas has no taste or smell. Often formed when hydrocarbon fuels burn in a limited supply of air, e.g., car engines especially in confined spaces, or gas-powered water heaters with poor ventilation. Every year causes many deaths in the home. Traces also occur in cigarette smoke and are implicated in heart and artery disease. For 15-minute exposure, concentration should not exceed 349 mg m⁻³. Forms explosive mixtures with air and oxygen. Mixtures with air between 12% and 74% carbon monoxide by volume are explosive.</td>
</tr>
</tbody>
</table>

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Carbon monoxide project work

You are a reporter for the magazine ‘Living in a scientific world’.

Your job is to investigate whether carbon monoxide really is a killer and what can be done to stop this deadly killer. The findings of the investigation should be written up for the magazine. Your editor will allow this feature article two sides of A4, she will expect it to be clearly illustrated with pictures, diagrams, charts and tables.

Your article should include the following:

- Evidence that carbon monoxide still kills in the late 1990s.
- The physical properties of carbon monoxide that make it a silent killer.
- Sources of carbon monoxide and the risk it poses in the home.
- The symptoms and science of carbon monoxide poisoning.
- Methods of detecting and alerting people to the presence of carbon monoxide.
- Recommendations for protecting your family from carbon monoxide poisoning.

Getting started

You will need to carry out some research. A good way to start is to work through some of the points listed below.

- A simple search of ‘Carbon Monoxide Poisoning’, on a CD-ROM such as ‘The Times’ newspaper, should bring up several up-to-date articles.
- Visit the following websites to find out about the symptoms of carbon monoxide poisoning, common questions and answers about carbon monoxide and the latest in carbon monoxide detection technology:
- Surf the web by doing a keyword search.
- Ask your teacher for a copy of the article, written by Rob Kingston, from Chemistry in Britain called ‘A detector calls’.
- Use a word processor, drawing or desktop publishing package to produce the final article.
A detector calls Smoke inhalation and carbon monoxide poisoning claim hundreds of lives every year. Rob Kingston looks at the detection technologies that can cut the death toll.

Smoke alarms save lives. It’s a familiar message and one that is borne out by statistics. In 1997, there were over 70,000 house fires in the UK, resulting in around 550 deaths. In those cases where a smoke alarm was present in the area of the fire, the death rate was around two deaths per 1000 fires, whereas where there was no alarm, this figure was nine per 1000. The overall rate of almost eight fatalities per 1000 fires reflects the sad fact that in only 30 per cent of cases was an alarm present in the area of the fire.

Fires in the home can spread with astonishing speed, releasing alarming quantities of smoke within minutes – and ironically, modern flame retardant materials may actually increase the production of toxic fumes (see Chem. Br., June 1998, p21 for a discussion of flame retardant technology). Smoke detectors, which are widely available for less than £30, can give an ear-piercing warning while a fire is still only smouldering, providing valuable extra minutes that can mean the difference between life and death for the occupants of a burning house.

Sniffing out smoke

But what actually goes on inside that little round white box with its flashing flashing light? All smoke alarms consist of two basic components: a sensor to detect smoke particles in the air and a siren to give the warning.

There are two common types of sensor in use in domestic smoke alarms: photoelectric and ionisation. The first of these simply uses light to ‘see’ the smoke. Inside the detector is a light source, such as a light bulb or a photoelectric cell — which produces a feeble electric current when light is shone on it — set back at 90 degrees to the light beam. When no smoke is present, the light beam passes straight across the detector and misses the photoelectric cell; so no current is produced. In the event of a fire, however, smoke particles enter the detector and scatter the light, reflecting some of it onto the cell (see Fig 1), and so producing a small current.

Once the amount of light falling onto the cell — and thus the current produced — reaches a set level then the siren is activated.

The second, and more common, type of sensor, is the ionisation detector, contains a very small amount (typically less than 0.2 mg) of americium-241 (see box 1), as the oxide (AmO2). Americium-241 emits both alpha particles and low energy gamma rays, but it is the alpha-particles that are vital to the operation of the detector.

The 241Am is situated in the ionisation chamber of the detector. This consists of two charged metal plates, one of which has a hole to allow the α-particles emitted by the radioactive source to pass through (Fig 2). The α-particles (αHe4) collide with molecules of oxygen
and nitrogen in the air between the plates, ionising them. A small electric current therefore flows continually between the charged plates, as long as the air is clear. If smoke particles, which are also highly ionised, enter the chamber they attach to the oxygen and nitrogen ions, neutralising them and disrupting the current. The control circuits of the detector sense this drop in current and activate the alarm.

It is difficult to say which is the better type of smoke alarm, because there are arguments for and against both types of sensor. Photoelectric detectors tend to be more expensive and less sensitive; however, they are better at detecting the large smoke particles that are produced by smouldering fires, and are less likely to give false alarms due to dust, or grease or steam from cooking. Ionisation detectors respond better to invisibly small particles, such as those produced by hot, blazing fires. Some authorities recommend installing at least one of each type so that a fire will be detected.

The silent killer

Fire is a very visible hazard. But a much more sinister killer, carbon monoxide, claims as many as 200 victims a year, according to Royal Society for the Prevention of Accidents (RoSPA) estimates. Earlier this year, the death of a family of four, who were overcome by the gas in their Derbyshire home, made headlines in the national press, but many other incidents go unreported.

CO is produced during incomplete combustion of fuels such as natural gas, oil, coal and wood. If it is breathed in, it enters the bloodstream where it binds to haemoglobin (Hb), forming carboxyhaemoglobin (COHb). Because CO binds much more strongly than O2 to haemoglobin, it effectively 'ties up' the Hb and reduces the oxygen-carrying capacity of the blood. If enough Hb is converted to COHb, the body becomes starved of oxygen, leading eventually to unconsciousness and death (see Table 1). And because COHb has a long half-life in the body — about five hours — even low concentrations of CO can, over time, lead to fatal levels of COHb in the blood.

The most frightening aspect of carbon monoxide is that it is completely invisible and odourless; hence, it is often unheeded because they are easily confused with the symptoms of common illnesses such as influenza.

However, detectors are available to alert people to the presence of CO in their homes, using a number of different detection methods. The first commercial sensor was the so-called Taguchi sensor (see Box 2), which was developed by Figaro Engineering of Osaka, Japan, in the 1960s. The Taguchi sensor is an example of a metal oxide semiconductor (MOS) sensor (see Box 2), and contains a heated tin oxide pellet, the conductivity of which varies according to the concentration of CO present, allowing a crude measure of ambient CO levels. MOS sensors are not ideal for home use, however: they are not specific to CO and can give false alarms with a number of substances such as hair spray, air fresheners or paint fumes. Another problem is that due to their high power requirements they must be mains-powered: an important consideration, because many CO poisoning incidents occur when appliances such as gas lamps and kerosene heaters are used during power cuts or in areas without an electricity supply. The need for mains power also dictates the positioning of such detectors in the home, because the intended location may not have a power socket nearby.

Despite these limitations, however, many of the CO detectors on sale today still use MOS technology.

Improved response

The first battery-powered CO detectors were made possible by using an optical detection technique based on chemistry. These so-called biomimetic sensors use a similar colour change to that which occurs in the formation of COHb in the blood, and are therefore more specific to carbon monoxide. However, because this type of sensor continuously absorbs even very low levels of CO that are always present in the air, it is difficult to obtain a reliable baseline from which to measure the concentration of gas present. Biomimetic sensor technology is still the subject of much research, however; Quantum Group, an environmental health company based in San Diego, CA, US, was the first company to produce commercial biomimetic technology-based CO sensors. Quantum's detectors use 'artificial haemoglobin', produced with the aid of genetically engineered organisms. These organisms produce molecular structures that resemble 'keyholes', the 'key' to which is the CO molecule. The presence of CO is detected by measuring the

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Table 1: The symptoms of carbon monoxide poisoning

<table>
<thead>
<tr>
<th>Level of COHb in blood (as percentage of Hb)</th>
<th>Symptoms and medical consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>No symptoms. Heavy smokers can have as much as 9 per cent COHb in their blood</td>
</tr>
<tr>
<td>15</td>
<td>Mild headache</td>
</tr>
<tr>
<td>25</td>
<td>Nausea and serious headache. Fairly quick recovery after treatment with oxygen and/or fresh air</td>
</tr>
<tr>
<td>30</td>
<td>Symptoms intensify. Potential for long-term effects especially in the case of infants, children, the elderly, victims of heart disease, and pregnant women</td>
</tr>
<tr>
<td>45</td>
<td>Unconsciousness</td>
</tr>
<tr>
<td>50+</td>
<td>Death</td>
</tr>
</tbody>
</table>

Source: Mikeal Volunteer Fire Department, US

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2. MOS sensors

The gas sensing element in a metal oxide semiconductor (MOS) sensor consists of two called-wire heating elements, separated by insulating material and embedded into a block of metal oxide semiconductor. The semiconductor used (typically tin oxide) is an n-type, in which electric current is predominantly carried by the flow of free electrons, as opposed to a p-type, in which the majority carriers are positively-charged holes in the conduction band.

Because the number of free carriers is a function of the surface temperature of the semiconductor, the heating elements are used to maintain a temperature of about 525°C. The high temperature also prevents water condensation forming on the surface of the semiconductor, which would reduce conductivity.

Usually the sensor detector surface has condensation from the air channeled onto it. When an oxidisable (ie reducing) gas such as CO is present, it reacts with the trapped oxygen, causing free electrons to be released into the semiconductor's conduction band and so increasing its surface conductivity. Note that any reducing gas will have this effect, so MOS sensors are not specific to carbon monoxide.
3. A quick check

Another type of CO detector is the EI200 CO Spot, produced by E.I. Electronics of Shannon, Ireland. This is a small self-adhesive plastic badge, which can be fixed to a wall near a potential source of carbon monoxide. On the badge is a small area of orange crystals, which turn black on exposure to carbon monoxide. Even a small colour change can be noted by comparing the colour of the crystals to the orange surround.

The chemistry involved is based on the Wacker reaction. The active part of the detector comprises a palladium(II) chloride dihydrate–copper(I) chloride catalyst system, which acts in a pseudo-homogeneous manner. The colour change is due to the palladium(I) being reduced to palladium(0). It is Pd metal.

The reaction is reversible, the key steps being set out below:

Reduction (occurs in the presence of CO): the carbon monoxide reacts with the palladium(II) chloride dihydrate, forming carbon dioxide and reducing Pd(II) to Pd(0):

\[
\text{CO} + \text{PdCl}_2\cdot2\text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{Pd} + 2\text{HCl} + \text{H}_2\text{O}
\]

Oxidative regeneration (occurs when the sensor is exposed to air which is free from CO): firstly, the palladium metal is oxidised back to Pd(II) by the copper(II) chloride (which is itself reduced to copper(I) chloride):

\[
\text{Pd} + 2\text{CuCl}_2\cdot2\text{H}_2\text{O} \rightarrow \text{PdCl}_2\cdot2\text{H}_2\text{O} + 2\text{CuCl}
\]

then the copper(I) chloride is oxidised back to copper(II) chloride by atmospheric oxygen:

\[
\text{CuCl}_2\cdot2\text{H}_2\text{O} + \text{H}_2\text{O} + \text{O}_2 \rightarrow 2\text{CuCl}_2\cdot2\text{H}_2\text{O}
\]

As can be seen from the above reactions, the presence and retention of both water and hydrogen chloride within the sensor is vital to allow proper, reversible functioning of the device. This is achieved by supporting the active crystals on a hydrophilic silica gel, incorporating a hygroscopic chloride-containing material such as calcium chloride, and adding strong acids such as sulfuric acid to the system.

While these detectors are very cheap, they do have their limitations. As with MOS sensors, gases other than CO such as ammonia and hydrogen sulphide cause false alarms, and the crystals gradually darken on exposure to the air even in the absence of CO. For this reason the badges have to be replaced every three months. However, they do provide a useful and affordable, ‘quick check’ for the presence of carbon monoxide.

<table>
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<th>Information</th>
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<tr>
<td>R.W. Bokobza and W.A. Stroth, Fire Journal, September 1976</td>
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<td>TSPSA: website, <a href="http://www.tspc.co.uk">www.tspc.co.uk</a></td>
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<tr>
<td>Quantum Group’s website, <a href="http://www.qane.com">www.qane.com</a></td>
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<td>Inland Volunteer Fire Department’s CO Frequency-Related Complaints, <a href="http://www.inoet.msp.mn.us/people/murn%E7%9A%84%E6%9C%80%E5%A4%A7.html">www.inoet.msp.mn.us/people/murn的最大.html</a></td>
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<tr>
<td>The Gas Analysis and Sensing Group (GASG) has produced a directory of gas-sensor research at UK universities. The 57-page directory is available in price £25 (£45 for overseas), from Dr. J. Watson, Chairgas, Bath Sensor and Sensing Group, Department of Electrical and Electronic Engineering, University of Wales, Swansea SA2 8PP, UK; tel: 01792-295415; fax: 01792-295608; email: <a href="mailto:welo@hplink.soton.ac.uk">welo@hplink.soton.ac.uk</a></td>
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Gas Association has created the International Approval Services (IAS) 696-98 standard, which is designed to reduce false alarms and false negatives, and to increase reliability, accuracy and repeatability. So far, says Kern, the only CO detector to meet the IAS 696-98 standard is that manufactured by his company. This detector has a patented self-testing mechanism that produces a small burst of hydrogen, by electrolysis moisture from the air, to test the sensor every 24 hours. The detector responds to hydrogen in a similar way to CO, so this system actually checks the operation of the sensor, unlike conventional test buttons that only test the alarm circuits. If the sensor fails to respond to the test, a malfunction alarm is sounded.

However, these detectors are not the end of the story. George Kern told Chemistry in Britain that Aim Safe-Air Products is currently collaborating with a British company, Analox Sensor Technology, to develop new CO sensors based on more advanced technology.

Other applications

The domestic detectors described here represent some of the most visible uses of chemical sensor technology – to the general public, at least. But other gas detectors are available that can measure levels of many different gases and vapours, including hydrogen sulphide, nitrogen oxides, sulphur dioxide, ozone, phosphine and hydrogen. Such detectors have many industrial and commercial applications, such as measuring levels of pollutants in exhaust gases, monitoring hazardous waste sites, and checking air quality in factories and offices. On spacecraft too, any build-up of toxic gases is potentially disastrous – as anyone familiar with the fate of Apollo 13 will know – so an early warning system is especially important.

For most of us though, smoke and carbon monoxide are more likely to be a worry. Fitting good quality alarms – and ensuring that they are properly installed and maintained – could be a lifesaver.

transmittance of light through the keyhole, using a light emitting diode (LED) source and a photodiode detector.

The most recently introduced type of detector, which is claimed to overcome the problems of other types, are those that make use of electrochemical technology. With this type of sensor, any CO that is present diffuses into the detector where it reacts with oxygen in the air, according to the general equation:

Sensing electrode:

\[
\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + 2\text{H}^+ + 2\text{e}^-
\]

Counter electrode:

\[
2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2
\]

Overall:

\[
\text{CO} + \text{O}_2 \rightarrow \text{CO}_2
\]

The current flowing between the two electrodes (through an external circuit) is proportional to the amount of CO present over a wide concentration range. This makes it possible for the detector to differentiate between acute, high concentrations and lower, but still hazardous level, and to give warnings accordingly. To avoid a build-up of carbon dioxide in the sensor, the electrode reactions take place under acidic conditions. Under these conditions the process needs a catalyst; platinum is usually chosen because it can form a range of chemisorbed surface species and so lower the activation energy of the intermolecular reactions. As a result, the response time of the electrode process is fast – it is measured in seconds.

Setting the standard

Among the most vociferous proponents of electrochemical detection technology is George Kern of Aim Safe-Air Products, a manufacturer of CO detectors based in Austin, Texas, US. Kern points out that even approved optical- and MOS-based detectors, which meet the required safety standards, often fail to operate correctly, either giving false alarms or—more seriously —failing to sound the alarm when dangerous concentrations of CO are present. Kern’s view is backed up by the Chicago-based Gas Research Institute (GRI), which in 1997 tested 96 CO detectors of different types, and concluded that electrochemical detection technology gave the best performance. The GRI’s report expressed concern that the existing North American safety standard (UL2034, 1994), act under Underwriters Laboratories (UL), an independent safety testing and certification organization based in Northbrook, Illinois, US) was not strict enough to ensure acceptable performance of detectors.

Partly due to this concern, the American