How do blood glucose meters work?

Marie Sherman <mriesherma@aol.com>
Ursuline Academy
341 S. Sappington Rd., St. Louis MO 63122

Introduction

Diabetes mellitus is a disease caused by the body's inability to produce insulin or to properly utilize insulin. Insulin is a hormone normally produced by the pancreas; its function is to enable cells to use glucose from the blood. Diabetes treatment consists of insulin injections, dietary control and/or various drugs.

The American Diabetes Association has reported that about 20 million people in the US (7% of the population) have diabetes, and there are many others who are not aware of their condition. In order to manage their diabetes, patients must frequently test their blood glucose levels. If glucose levels are properly controlled, some of the serious complications of diabetes, such as blindness, amputations and kidney failure, can be prevented.[1] In the mid-1990s small hand-held electronic glucose sensors were introduced and soon accepted by diabetics. They were able to test their blood several times a day, and thus adjust their food intake and insulin dosage to achieve normal glucose levels. By 2005, world wide glucose-monitoring sales were estimated at approximately $5 billion US.[2] How do these electronic marvels work? It's all chemistry, specifically electrochemistry.

The Testing Device

The testing device consists of a small, palm-sized, battery-powered meter about 5 cm x 9 cm and 1.5 cm thick, with a display screen about 3 cm x 4 cm. See below for pictures of typical glucose devices out of the many that are available. The test strips are inserted into a small opening on the top or bottom edge. (The shape of the strip is specially designed so that it cannot be inserted incorrectly.) The electrochemistry of the strip is the key to the operation of the glucose sensor.

Abbott Bayer LifeScan – Johnson &Johnson

The ingredients of a typical test strip are as follows:
~29% w/w glucose oxidase (from *Aspergillus niger*, a fungus), 20U/mg
~32%w/w potassium ferricyanide
~39% w/w nonreactive ingredients[3]

On each strip, there are about 10 layers, including a stiff plastic base plate, and other layers containing chemicals or acting as spacers. For instance, there is a layer containing two electrodes (silver or other similar metal). There also is a layer of the immobilized enzyme, glucose oxidase, and another layer containing microcrystalline potassium ferricyanide, $[K_3Fe(CN)_6]$. These layers are suitably separated by the spacers to allow a small amount of blood to enter.[4] When the end of a strip is touched to a droplet of blood (usually on a fingertip), the blood flows in by capillary action. A "beep" sounds, signalling that testing has begun. In some models, a digital display on the screen "counts down" the seconds till the concentration of glucose is displayed. In the US and Canada, the blood glucose concentration is reported in milligrams per deciliter (mg/dL). However, in Europe the standard is millimoles per liter (mmol/L).[1]

Chemical reaction of the glucose sensor

The chemical reactions in the sensor are shown in Figure 1. The glucose in the blood sample reacts with the glucose oxidase to form gluconic acid, which then reacts with ferricyanide to form ferrocyanide. The electrode oxidizes the ferrocyanide, and this generates a current directly proportional to the glucose concentration.[5]

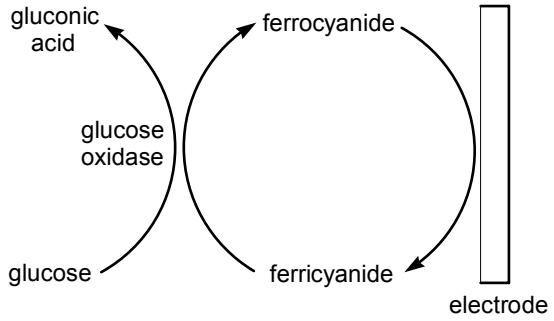


Figure 1. The chemical reactions in a glucose monitoring sensor. *(Redrawn from reference 5.)*

Glucose Oxidase

Glucose oxidase (Enzyme Commission No. 1.1.3.4) is obtained from the fungus, *Aspergillus niger.* It is a dimeric protein with a molecular weight of about 160 kD. It is strongly specific for beta-D-glucose (the type of glucose in blood), although 2-deoxy-D-glucose, D-mannose and D-fructose also can be oxidized, but at a much slower rate.[6] The normal reaction of glucose oxidase is shown below:[7]

$$\beta\text{-D-glucose} + O_2 \xrightarrow[\text{phosphate buffer, pH 7.3}]{\text{glucose oxidase}} \text{gluconic acid} + H_2O_2$$

Potassium ferricyanide

The systematic name is potassium hexacyanoferrate(III), but it is also known as red prussiate or Prussian red, because of its ruby red color. It is a relatively inexpensive chemical and easily obtained. Over the years, it has found many uses as a mild oxidizing agent, in photography, blueprinting, in electroplating and dyeing wool.[8]

In addition to potassium ferricyanide, other chemicals such as quinone and ferrocene compounds and 2,6-dichloroindophenol have been found to be suitable electron acceptors in this reaction.[9,10]

Conclusion

These devices can be adapted for use in a high school chemistry classroom. For example, an experiment to the test efficiency of over-the-counter lactose intolerance medication was described in the October issue of *Chem 13 News*.[11] Another experiment is the studying of the action of the commercial product Beano.[12] Also kinetic reactions could be studied in which glucose was either a reactant or product.

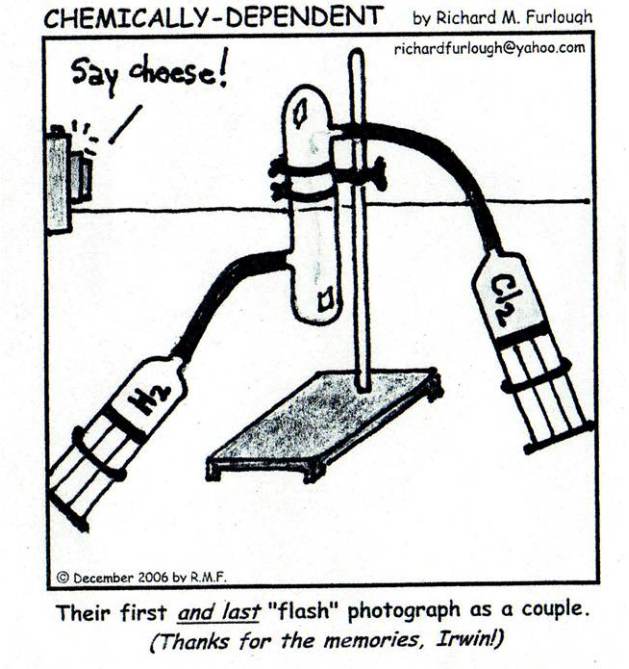
And, last but not least, the glucose monitor is a good example of an application of electrochemistry.

References

1. C. Rados, *FDA Consumer*, March/April 2006, pages 6-7.
2. N. Adler, *Washington Business Journal*, Nov. 3, 2005.
3. Bayer Ascensia Elite blood glucose test strips package insert, 2002.
4. U.S. Patents 5, 120, 420 and 5, 320, 732.
5. L. Kuhn, *The Electrochemical Society* Interface, Winter 1998, pages 26-31.
6. *http://chem.ch.huji.ac.il/~eugeniik/glucose_oxidase.htm*
7. G. Sittampalam and G.S. Wilson, *Journal of Chemical Education*, January 1982, pages 70-73.
8. *http://en.wikipedia.org/wiki/Potassium_ferricyanide*
9. *http://www.ncbi.nih.gov.entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=15228088&dopt=Abstract*
10. J. Wang and C. Macca, *Journal of Chemical Education*, August 1996, pages 797-800.
11. Marie Sherman & Mary Walsh, *Chem 13 News,* October 2006, pages 6-7.
12. J.R. Hardee, T.M. Montgomery and W.H. Jones, *Journal of Chemical Education*, April 2000, pages 498-500. ■

Chem humour

I was teaching my AP students organic chemistry, and when I got to aldehydes, I gave them the formula for methanal (formaldehyde), CH_2O. One of my students, (Tess Jarusiripipat), said "C" water. I thought it was worth passing along. *(Curtis A. Musser, Cate School, 1960 Cate Mesa Road, Carpinteria CA 93014)*



Their first *and last* "flash" photograph as a couple.
(Thanks for the memories, Irwin!)

A Su-chem-du with message

This Su-chem-du has a wintry message in the first row. Here is a clue. The message is "what one does while doing a Su-chem-du in the winter."

Everything else is the same as our usual Su-chem-du. Each of the nine chemical symbols is to appear once in each row, column and each 3x3 square. At the bottom of the puzzle is the list of elements to be used. We'll draw the winner of a periodic table from the correct entries on February 12, 2007. Send your entry to *Chem 13 News* Su-chem-du Message, Department of Chemistry, University of Waterloo, Waterloo ON N2L 3G1. Fax: 519-888-9168. E-mail: kjackson@uwaterloo.ca.

Si				**Tc**				**Te**
	Te			**H**			**O**	
		O			**Co**	**Ho**		
			Si		**Te**	**H**		
Tc	**O**						**P**	**Ho**
		La	**Tc**		**P**			
		Tc	**P**			**La**		
	H			**Co**			**Si**	
Ho				**Te**				**O**

Co	H	Ho	La	O	P	Si	Tc	Te