Amber: an introduction to organic chemistry Blue Dominican amber, 25-40 million years old

Did you know that the electron and electricity are named after amber, the 'gold' of the Baltic Sea? **Bernhard Sturm's** teaching unit based on this fossilised resin introduces not only conductivity but also many other characteristics of solid organic compounds.

Introduction

Amber has been used as jewellery, as an ingredient in perfumes and in folk medicine for thousands of years - but it also has its place in science. It was the first substance on which electrostatic phenomena were observed, by the Greek philosopher Thales of Miletus, 600 BC, and it gave electricity its name: in 1601, the English physicist William Gilbert, the first to distinguish between magnetic and electrical attraction, coined the term 'electricus' for the property of attracting small objects after being rubbed, derived from amber's Greek name elektron (meaning shiny).

Amber is plant resin that fossilised either inside the plant, or after oozing out from it. Pieces of amber can be 20 to 320 million years old, but it is difficult to be certain: radiocarbon dating can only be used for specimens up to 50 000 years of age. So you have to determine the age of the surrounding

sediment, which can be misleading because the amber may have originated far from the location in which it was discovered. Although amber is found all over the world, including in the Dominican Republic where rare blue amber is mined, possibly its most famous deposits in Europe are in the Baltic Sea, where large quantities are found. Yet amber is also found in eastern Europe, the North Sea, the Alps, northern Spain and Sicily. Pieces of amber torn from the sea floor are cast up by the waves and collected by hand, dredging or diving. Elsewhere, amber is mined, both in open works and in underground galleries.

The heterogeneous yellow to red organic macromolecule fossilises from two types of soft, sticky plant resin: terpenoid resins or phenolic resins. Terpenoid resins, produced by both conifers and angiosperms (flowering plants), consist of ring structures formed from isoprene (C_5H_8) units. Phenolic resins are found only in angiosperms, and include lignins, flavonoids and certain pigments.

An amber inclusion

Resins protect injured plants from further damage, oozing out and hardening to form a defence against invading fungi and insects. The volatile fractions of resins are scented (think of the typical scent of pine

Teaching activities



Amber sources in Europe. Amber discovery locations in red, historical amber routes in black and red, rivers in blue



Amber 'baby chains' like this one are very useful for the experiments

resin), but it is the sticky, non-volatile, di- (C_{20}) and tri-terpenoid (C_{30}) fractions that fossilise into amber via free-radical polymerisation. During this maturation process, which takes place over millions of years, polymerisation, isomerisation, cross-linking T_{20} and tri-terpenoid (C_{30}) fractions that fossilise into amber via formula $C_{10}H_{16}$ O. A small amount of sulphur (up to 1%) may also be included. Since amber has many classical properties of solid organic compounds, such as being combustible, not conducting electricity and being electrostatically chargeable, it is a good model substance to introduce these compounds in general, despite its varied and complex composition. It offers the added value of putting

Chemistry

Organic chemistry

- Physics
- Biology
- Earth science
- Environmental science
- Arts and crafts
- ✓ Ages 16+

Bernhard Sturm, who has already published another enjoyable article in *Science in School* (Sturm, 2009), is a model of creativity in the field of science teaching.

Those who think that chemistry and physics are boring subjects should try the activities based on amber proposed by the author. Starting from this ancient material and following the suggested links, a science teacher can explore many different topics related to amber and discover unexpected relationships with arts and humanities.

The different core activities, in fact, provide the opportunity to address organic chemistry (natural and manmade polymers), earth science (sedimentary rocks, fossils, fossil fuels), physics (density, separation methods, conductivity and charge separation), environmental science (combustion, pollution) and biology (plant resins, amber inclusions). For those interested in interdisciplinary links, the choice is also wide: arts and crafts (making jewellery), history (the Amber Road, the Amber Room) or economy (amber mining and commerce), just to mention some.

Finally, a teacher only needs to get some pieces of the 'gold of the Baltic Sea' (which is – luckily – much cheaper than true gold) to follow Bernhard Sturm in the footsteps of Thales of Miletus, William Gilbert and others.

The article might provide valuable background reading for a visit to a natural history or science museum and can also be used as a comprehension exercise. Possible questions include:

- 1. To assess the age of a piece of amber:
 - a) radiocarbon can normally be used
 - b) it is necessary to date the surrounding sediments
 - c) different methods are used depending on the circumstances.
- 2. Which of the following materials is most different in density compared to amber?
 - a) polyethylene
 - b) polyvinylchloride
 - c) oak wood
 - d) colophony.

Giulia Realdon, Italy

chemistry into a broader context, thus appealing to students who are not normally interested in the subject, because there are links to arts, biology, earth science and physics.

This five-lesson teaching unit is suitable for students aged 16+ who already know about density, conductivity and the electric circuit. You may want to provide textbooks from earlier grades for the students to refresh their knowledge. The teaching unit consists of six core activities: over four lessons of 45 minutes each, groups of students rotate through the stations, so that each group performs all the activities. Each activity will take about 20 minutes. In a large class, it may be useful to provide two of each station. In the final lesson, the students present their results in class.

It is possible to extend the teaching unit with additional optional activities (see below), which may involve colleagues from other subjects. Alternatively, you may perform all or part of the activities as demonstration experiments or by the entire class simultaneously. The methods used in the different activities are quite varied, and the results tend to be easily remembered by the students.

The amber required for these activities can easily be obtained through online shops. One 30-35cm-long 'baby chain' for teething babies, available for about €8-20, will suffice to perform all core activities with about 30 students. Often, students are also keen to take family jewellery into class. The only experiment that will actually use up or damage the amber is combustion.

Core activities

For those students who are especially fast, you may want to provide further organic compounds on which they can perform the same experiments and compare to amber. These can be: for Experiment 2, other

	Crude oil		Coal		Amber	
Source	Time of origin	Formation	Time of origin	Formation	Time of origin	Formation
dtv-Lexikon, Munich, 1966	Creta- ceous, 145-65 million years ago	Small organisms sank to the bot- tom of the sea, forming sapropel (organic sludge); they were digested in the sediment under anaerobic condi- tions and high pressure	Carbonifer- ous, 360- 300 million years ago	Dead tropical plants sank into the mud where they were covered by sand and clay; high pressure and anaerobic conditions led to carbon- isation	Devonian to Tertiary, 400-40 million years ago	Resin oozed from trees to the ground, sank below the sea level after the climate changed, and polymerised under anaerobic conditions
http://en. wikipedia.org accessed on 31/03/2011	Millions of years ago	Large quantities of prehistoric zooplankton and algae settled on the bottom of a water body under anoxic conditions; the organic mat- ter mixed with mud and was buried under sediment; heat and pressure led to formation of crude oil	Carbonifer- ous (359- 299 million years ago)	Layers of plant matter accumulated at the bottom of a body of water; mud or acidic water protected them from biodegrada- tion and oxi- disation; they were covered by sediment and metamor- phosed into coal	Upper Carbonif- erous (320 mil- lion years ago) and later	Resin that was either still in the plant or had oozed out and dropped to the ground, often acquiring impurities; high temperatures and pressures due to overly- ing sediments first led to formation of copal (an intermediate stage of polymerisation and hardening, between 'gummier' resins and amber); sustained heat and pressure drove off terpenes, resulting in amber formation

Table 1: Geological origin of crude oil, coal and amber

Teaching activities

Images courtesy of Bernhard Sturm



Comparing the flames of burning organic compounds

saturated organic compounds such as alkanes, e.g. in the form of a gas burner (with a yellow flame) and a lighter; for Experiments 3 to 6, plastics such as polyvinylchloride and polyethylene, as well as different types of wood (for example pine and oak, e.g. from a set of density cubes) and colophony (violin rosin, used to rub the hairs of the bow).

1) Geological origin

The students should compare the date and process of formation for natural deposits of amber, crude oil and coal by performing Internet and literature searches. They should critically evaluate the reliability of different sources of information and note down the dates and processes given in the different sources. For websites, they should note down the date at which they were accessed. See Table 1 for an example of what they may find.

2) Combustion

Remind your students that high levels of carbon in a burning organic substance will lead to a sooty flame. The students should then hold a piece of amber (German *Bernstein* = Börnsteen = burning stone) with a pair of crucible tongs below a glass test tube, then burn the amber with a match and watch the soot collecting on the test tube.

To link the activity to the topic of particulate matter pollution by combustion engines, the students can vary the combustion conditions of a Bunsen burner by opening and closing the draft, and discuss how to avoid soot production.

Safety note: wear safety goggles and do not overheat the glass, as it may explode. Do not burn polyvinylchloride (available as optional material for Experiments 3 to 6), which would result in the production of harmful dioxins. See also the general safety note on the *Science in School* website (www.scienceinschool.org/ safety) and on page 73.

3) Density

The students should determine the density of amber (1.050–1.096 g/ml), which is only slightly higher than that of water (about 0.998 g/ml at room temperature). For this experiment, more accurate results will be achieved using a larger piece of amber with no hole in it. I own a large piece of amber and a piece of flint of comparable size and like to give both to the students, asking them to determine which is

Image courtesy of Bernhard Sturm



Amber (in front) and flint (on the balance) can be distinguished by determining their density

which by measuring their densities.

You will need a piece of amber, a measuring cylinder, water (containing a small drop of washing-up liquid to reduce the surface tension and improve the accuracy of measurements) and a balance.

Weigh the piece of amber. Partly fill the cylinder with water and note down the volume of water. Add the amber and note the difference in volume. Calculate the density of amber as:

Density of amber [g/ml] = weight of amber [g] / (volume with amber [ml] – volume without amber [ml])

Many organic compounds have densities similar to water (0.8–1.2 g/ml). Polyvinylchloride is atypical, with a density of 1.4 g/ml, due to its heavier chloride atoms.

4) Separating amber from a mixture of organic and inorganic compounds

The students will learn how to separate amber from rocks and sand, an experiment with practical relevance for amber mining.

- 1. Weigh an empty beaker.
- 2. Add a defined volume of water and weigh it again to determine the mass of the water.
- 3. Next add a mixture of sand, rocks and amber, and weigh the beaker again. Also note down the volume contained.
- 4. Gradually add salt and mix until the amber floats. Weigh the full beaker again and note down the volume contained.

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Classification of amber

Plant resins are so diverse that their distinct chemical composition is used to identify from which plant species a piece of amber formed. This does not mean that similar resins must originate from similar plants, however: recent research has revealed that resins of extremely similar molecular composition can be produced by entirely unrelated plants (Bray & Anderson, 2009) – the distinctions can be quite small. On the basis of their chemical constituents, five classes of amber are roughly defined:

• **Class I:** by far the most abundant, comprising labdatriene carboxylic acids; three subclasses

8(17),12,14-Labdatriene-19-oic acid, also known as communic acid



 Class II: formed from resins with a sesquiterpenoid base, such as cadinene

Cadinenes, such as $+-(\alpha)$ - cadinene, are found in a variety of essential-oilproducing plants including the Cade juniper (*Juniperus oxycedrus*)



Class III: natural polystyrenes

Polystyrene forms by polymerisation of styrene units



 Class IV: a collection of non-polymerised ambers which consist mainly of cedrane-based sesquiterpenoids



Cedrol, a common cedrane found in cedar oil

 Class V: considered to be produced by a pine or pine relative; a mixture of diterpenoid resins and n-alkyl compounds (R-NH-CH3) Labdane, a diterpene originally obtained from labdanum, a resin derived from rockroses (*Cistaceae*) What is the density of the salt water? Calculate it as:

Density of salt water [g/l] = [(mass of beaker at the end (step 4) – mass of beaker before salt is added (step 3)) + (mass of beaker with water (step 2) – mass of empty beaker (step 1))] / [volume of water + (volume of beaker at the end (step 4) – volume of beaker wihout salt (step 3))]

This should of course be higher (>1.1 g/ml) than the density of amber determined in Experiment 3, otherwise the amber would not float.

The students should illustrate their ideas of how this technique could be developed into a technology for continuously mining amber (see image on page 41).

5) Conductivity

The students will learn that solid organic compounds do not conduct electricity, by building an electric circuit using a power supply, three cables and a light bulb to test the conductivity of amber. If they are not familiar with the experimental setup, you could supply a physics textbook for them to look it up.



6) Charge separation

The students will learn about electrostatic induction and charge separation, performing Gilbert's electrostatic experiment: they rub a piece of amber with wool and see that it attracts small pieces of paper or, for example, the dried pith from the centre of an elder (*Sambucus* spp.) twig. This also works well with the small pieces of amber from a baby chain.

The experiment will not work well if the air is humid, because water in the

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Teaching activities



air will conduct electricity and reduce the electrostatic charge on the amber. Damp fingers will do the same; for better results, the students could use insulated (plastic) tweezers to hold the amber.

Optional activities Making jewellery

To link art and chemistry and foster your students' technical skills, you could get them to produce their own amber jewellery. You will need raw amber pieces of at least 15 mm in diameter. Sand the piece of amber with wet fine sandpaper (Coated Abrasive Manufacturers Institute grit size 120–1000), then polish it with toothpaste. Rinse with water and dry with kitchen roll, then rub in some cooking oil using a cloth. Pierce the amber with a hot needle (this should be done by the teacher) or drill a small 1-2 mm hole. Thread the amber onto a nylon or leather string to make a necklace or bracelet.

Links to biology

For a link to biology, the students can look at inclusions in amber and discuss tree resins in depth – what is their composition, where do they occur, what is their function and what is the structure of wood?

Opaque amber

Image courtesy of V Girard / D Néraudeau, UMR CNRS 6118

Amber research at ESRF

Pieces of amber are a rich source of fossil evidence. At the European Synchrotron Radiation Faciliy (ESRF)^{w1} in Grenoble, France, powerful X-rays are used to study inclusions in amber. This is especially useful for opaque amber pieces, which are inaccessible to palaeontologists with classical microscopy techniques. Several hundred animal inclusions from the mid-Cretaceous, 100 million years ago, have been identified.

In another study at ESRF, researchers used the same technique to obtain detailed three-dimensional images of feathers enclosed in translucent amber, which may have belonged to a feathered dinosaur – an intermediate in the evolution to modern birds.

For more information, read the online report^{w2} from ESRF, one of the members of EIROforum, the publisher of *Science in School*.

3D reconstruction of a hymenopteran insect of the *Falciformicidae* family, embedded in 100-million-year-old opaque amber

3D reconstruction of a feather intermediate between dinosaurs and modern birds, enclosed in amber

BACKGROUND

200 µm

References

Bray PS, Anderson KB (2009) Identification of carboniferous (320 million years old) class Ic amber. Science 326(5949): 132-134. doi: 10.1126/ science.1177539

The free full-text article is available online.

For drama activities in the chemistry and physics classroom, including one about the radical polymerisation of ethene to polyethylene in class, see:

Sturm B (2009) The drama of science. Science in School 13: 29-33. www.scienceinschool.org/2009/ issue13/drama

Web references

w1 - For more information on ESRF, see: www.esrf.eu

w2 - Scientists at ESRF used powerful X-rays to study amber inclusions. See: www.esrf.eu/news/general/ amber

Resources

- To download charts of Earth's history, see: www.stratigraphy.org/upload/ ISChart2009.pdf or www.chronos. org/downloads/timetowerparis_ highres.png
- To learn about research into biodegradable plastics, see:

Bradley D (2007) Plastics, naturally. Science in School 5: 66-69. www.scienceinschool.org/2007/ issue5/plastics

If you enjoyed reading this article, why not take a look at the full collection of articles on chemistry published in Science in School? See: www.scienceinschool.org/chemistry

Bernhard Sturm obtained his PhD in chemistry at the GKSS Research Centre Geesthacht, Germany. He teaches chemistry and physics at the Neues Gymnasium, a secondary school in Oldenburg, Germany. His main interest is interdisciplinary work linking science and humanities. His students have won a number of science competitions on geoscientific and climate topics. This led to Bernhard winning the Lower Saxony Teacher's Award for STEM subjects in 2010.

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To learn how to use this code, see



page 1.

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