Case Study Exchange Format – HIPST
Acidity

Details of section	Guidance
1. Title	Is acidity perfect or real? Key words: acid, acidity, idealisation, induction
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3. Abstract	The activity is relevant to lower secondary school science, and for all abilities. The theme of acidity is commonly treated in lower secondary schools, with occasional reference to 'everyday' science such as treating wasp and bee stings. In this topic for the HIPST project, we aim to set the topic firmly in a historical and philosophical context. The progression of ideas about acidity, beginning with the uniquely dangerous, and possibly fatal, classification based on taste, through its effect, at first, on home-made medicines that were useful as indicators of acidity, and finally searching for the magic ingredient (oxygen or hydrogen?) is an amazing story that covered many centuries, but finished nearly two hundred years ago with Sir Humphrey Davy. Yet these ideas are still commonly in use today, not only in the upper reaches of schools (A level and other pre-university courses) but even among some research chemists who continue to base some of their thinking about acidity in organic materials on hydrogen atoms that can be replaced by a metal. While the story can be ended at the Davy idea of replaceable hydrogen atoms, it leaves open development to other ideas. Much of the language we use about acidity, such as neutralisation, comes from medieval power politics where great powers neutralised each other through pitting equally strong armies against each other. They were thought to be equivalent to each other, and the notion of equivalence is fundamental to salt preparation. Although, at first sight, the topic appears to be phenomenological and largely descriptive, the philosophical problem of characterising a chemical class boundary through the reactions of imperfect acids is solved through induction to realise the intangible concept of the Ideal or Perfect Acid. Philosophical considerations of 'explanation' based on cause and effect drive the search for the magic ingredient that is at the heart of all acids, even giving an element its name of oxygen from the Greek 'sour maker'. This search drew evidence from practical knowledge such as combustion of sulphur and phosphorus to make acrid (from Latin: sharp) smoke, suggesting that acids contained something that made them acidic. Of course, the role of water in taste was not considered, and, for example, sulphur oxide was named as sulphuric acid. Nevertheless, the oxygen containing theory was very comforting, until the chemists discovered an acid that did not contain oxygen, hydrochloric acid, when chlorine was shown to be an element. There followed a period of 'accommodation' where two kinds of acids

	were proposed, ones containing oxygen and ones containing hydrogen. The story stops here, as it did for many chemists who never knew about the contribution of Arrhenius.
4. Context	The Case Study Introducing HPS in the school chemistry curriculum is a relatively recent activity for curriculum designers and researchers, compared with physics. There are significant reasons for this. 1. There are few recognised paradigm changes in chemistry compared, for example, with physics. The usual ones quoted include the phlogiston idea, although this only lasted for 50 years in history, and quantum mechanics, which is, perhaps, more properly located in physics. 2. There are few historical artefacts that have lasted in chemistry, compared with physics which has abundant examples. Partly this is because chemistry widely used glass apparatus which is fragile and easily destroyed. Partly it is because some of the equipment, such as the balance, were considered to be so common-place that they were simply not worth saving or recording. Partly it is because the furnaces that were used were destroyed. Finally, partly it is because many of the early chemical discoveries were based on phenomena, and not on measuring instruments. 3. The structure of the chemistry curriculum in schools is such that phenomenological investigations abound at junior levels, and quantitative considerations, such as calculations based on chemical formulae and chemical equations are treated and assessed in an algorithmic way. The topic is initially about acidity, a well defined topic in historical terms. We have chosen to use much of the traditional material, since it largely parallel to the historical line. Where it differs is in making explicit historical incidents. The origins of ideas about acidity are largely lost in the mists of history. An Arabic alchemist, abir ibn Hayyan Geber, had made a wide variety of acids around AD 750. his acids included sulphuric, nitric, citric, and malonic. Many alchemists also knew about the effect of these and other acids on limestone and marble. Robert Boyle, in 1670, knew that an acid gives hydrogen with a metal such as zinc, or iron, although he would not be sure about the chemical nature of hydrogen. Boyle also invented the use of everyday indicators such as Syrup of Violets, a household medicine, for testing acidity. The term alkali came from the Arabic for the ashes left in the roasting pan. Boyle knew that acids and alkalis, or bases, could neutralise each other and chemists/ alchemists previously had studied the salts formed. Based on alchemy, many chemists were searching for magic ingredients. Lavoisier had known that many acidic substances, such as sulphur oxide and phosphorus oxide, had been formed by burning the non-metal in his newly-named oxygen (Greek: acid maker) and that acids therefore contained oxygen. Lavoisier understood sulphur oxide to be sulphuric acid (French: acide sulphurique) and that its solution in water, which we now call sulphuric acid, was sulphuric acid hydrate. Not knowing the function of the water as a chemical here, it is not surprising that Lavoisier did not appreciate what was going on. In 1818, Davy showed that hydrochloric acid was made up of only hydrogen and chlorine with no oxygen. This led to the idea that there were two kinds of acid, the oxoacids and the hydracids. This was resolved later in the century when it was proposed by Arrhenius that all acids in water have off hydrogen ions, more or less. The action of creating a class of substances known as acids is a process of induction. Although many acids have similar properties (turning vegetable dyes red or orange or yellow, reacting with zinc and iron, reacting with carbonates, making salts with bases) here are enough exceptions to make the classification unclear. In the Case Study, we discuss the notion of an Ideal or Perfect Acid, which has all the acidic features, and which we create based on the imperfect acids by their reactions. This is a challenging idea. We finish the cognitive aspect by exploring whether an acid always has oxygen or whether it might have hydrogen. This is a modest paradigm shift in chemistry, not always recognised by philosophers. Finally, we use various reflective devices to explore both their understanding of the chronology of discovery,

	and the philosophical processes that have taken place. We have used links to Drama in producing play scripts of historical events, and to English in the form of newspapers to present historical information. There are strong links to History in the cultural background of the scientific exploration. A homework box for students to record their thinking about idealisation on the outside provided an insight into their progress, and a card sort enabled them to discuss their view about the chronology of ideas about acidity.
5. Topic and curricular relevance	The target group in England is 11-12 year old students, in schools. The scientific concepts and processes include: *Concepts* • Characterising the concept of acidity in terms of behaviour • Ideas about vegetable indicators • Chemical reaction • Acid-metal reactions as phenomena • Acid carbonate reactions as phenomena *Processes* • Establishing the boundary of a chemical group such as acids • Idealising the nature of an ideal acid from real acids *History of science* • Establishing ideas about acids as substances that react with bases • Establishing ideas about acids as substances that react with some metals • Establishing ideas about acids as substances that can turn vegetable dyes red, orange or yellow • Acids as containing oxygen • Acids as containing hydrogen *Nature of Science* • Characterising a class of materials based on behaviour, e.g. acids • Searching for a cause and effect explanation through a 'magic ingredient' oxygen • Paradigm shift from oxygen-containing to hydrogen-containing • Know about the nature of idealisation **Expected outcomes of learning** *Concepts* • Know how to characterise acids in terms of behaviour with vegetable dyes, carbonates and some metals • Know about how acids interact with vegetable dyes • Know about acid-metal reactions as phenomena • Know about acid carbonate reactions as phenomena *Processes* • Know how to establish the boundary of a chemical group such as acids

	• Know how to idealise the nature of an ideal acid from real acids *Nature of science* • Know about characterising a class of materials based on behaviour, e.g. acids • Know how to search for a cause and effect explanation through a ‘magic ingredient’ oxygen • Know about the shift of ideas about acidity from oxygen-containing to hydrogen-containing • Know about the nature of idealisation *History of science* • Establishing ideas about acids as substances that react with bases • Establishing ideas about acids as substances that react with some metals • Establishing ideas about acids as substances that can turn vegetable dyes red, orange or yellow • Know about acids as containing oxygen • Know about acids as containing hydrogen • Know about Boyle’s use of vegetable dyes as indicators *Links to formal science content* ‘They trace the development of science worldwide and recognise its cultural significance.’ (QCDA, 2007, England National Curriculum) ‘They describe some evidence for some accepted scientific ideas, such as the patterns in the reactions of acids with metals and the reactions of a variety of substances with oxygen.’ (QCDA, 2007, England National Curriculum) The new National Curriculum (2007) in England has no direct references to History and Philosophy of Science ideas, and textbooks rarely refer to history of chemistry except for brief biographical notes on some memorable scientists. Development of science is almost always in terms of contemporary science. Philosophy of science, as in scientific method, is a limited view position based on Popperian logic of testing theories with data in a positivist way. *Expected effects on student interest and motivation* • Expected that students would be excited by spectacular practical work, and they were. • Expected that students would be engaged in reflection activity that dealt with *Expected learning of general scientific skills such as communication, socio-scientific decision-making, and collaborative learning.* • There was evidence that some gain in communication skills from a few students had occurred • We did not investigate socio-scientific decision-making in this topic • Some collaborative learning took place in the group practical work and in the reflection activity.
6. Historical background	Much of the detailed material is in the newspapers attached to this Case Study. This should be at an appropriate level for historical and

7. Social, political, and cultural background to history	philosophical novices. • Alchemists were aware of many acids from AD 750 onwards, although it is not clear from their writings how much they were explicit about their nature as a class of chemicals. • Acids were first classified by taste (Latin: acetum sour), and acids are probably the only class of chemicals to be identified this way. • 'The conceptual division of certain substances into acids and bases was already evident in the Middle Ages, the terms "acid", "base", and "salt" occurring in the writing of medieval alchemists. Acids were probably the first to be recognized, apparently because of their sour taste: The English word "acid", the French word "acide", the German "Sauer", and the Russian "kislota" are all derived from words meaning "sour".' http://ravialchemy.blogspot.com/2007/11/acid-base-history_20.html • Boyle popularised the use of vegetable dyes as acid indicators, around 1670. Most of these dyes were already known as home medical remedies, such as Syrup of Violets. This link between medicine and chemistry was more common than we commonly imagine. Many early researchers in chemistry worked in pharmacies, or were Professors of Medicine. • Boyle also published his knowledge that acids gave a flammable gas (now known as hydrogen) with some metals such as zinc and iron. • Nicholas Lemery tried to explain (1680) how acids tasted sour by imagining that they had particles with points on them. This is a cause and effect explanation. • Lavoisier used his oxygen theory of acids to create a new nomenclature system with some of his fellow chemists (1787) to aid learning in a systematic way. • Davy, in 1810, showed that chlorine was an element, and that hydrochloric acid contained no oxygen. He created the idea that all acids contained hydrogen, but it took many years before textbooks adopted this. Wilson, writing in 1856, described two kinds of acids, oxo-acids and hydracids. • Arrhenius, in 1884, put forward the thesis that acids form hydrogen ions when in water, using electrical conductivity equipment invented for the new telegraph industry in 1840 by Kohlrausch. • The progression of ideas about acidity moved from a descriptive basis for a class of chemicals (the idea of an Ideal or Perfect Acid), to a causal effect based on acids containing oxygen, then hydrogen. The idea that it was a component of the acid that made it acidic, changed when Arrhenius proposed that a new species, the hydrogen ion, was the cause of acidity. Further ideas were proposed in the 20^{th} century but are not mentioned here as they are not used in this unit of work.

8. Philosophical background, including the Nature of Science	This is also described above as part of the social, political and historical background.
9. Obstacles to teaching and learning	The material given here is mainly from Driver *et al*(1994) Making Sense of Secondary Science published by Routledge Carr has suggested that pupils' ideas about acids are derived from everyday sensory experiences, such as tasting sour milk, vinegar and citrus fruits, and from cartoons and crime stories about acid baths, advertisements for ant-acid remedies, and, perhaps, news about acid rain. Hand and Treagust report that 15 year old pupils focus on phrases such as 'acids eat material away' and 'acids can burn you'. Indeed, the terms corrode and erode come from the Latin, rodeo, to eat into or to gnaw into, and we get the word 'rodent' from the same derivation. The ideas provide the idea of how to test an acid, by seeing if it can eat away at something. What chemists think of typical acidic reactions are largely unknown to pupils from their everyday life, so that there is an open door here to expose these pupils to the peculiar ideas of the chemists. Hand suggested that it was not easy to change these everyday notions simply by transmissive teaching. There are a number of concepts about acids, as the Scheme of Work indicates, and chemists seem to flip easily from one to another (and from macroscopic to symbolic) which makes it difficult for the learners to follow a discussion. In the teaching unit, great focus was laid on identifying the nature of the behaviour of acids, and thence to the nature of acidity, largely through historical explorations for the search for the elusive nature of what an acid is. A major obstacle that arose during the implementation of this project was the behaviour of acid indicators. Typical acid indicators have colours that vary from red, through orange, to yellow. If we take the normal teaching sequence, then those can be explained simply as the acid indicator colours, and teachers are not known to question this. However, in this sequence, where we intended to take common behaviour and induce the behaviour of the ideal, the varying acid colours proved to be an obstacle. To the pupils, red, orange and yellow are different, not similar! We finished up just telling the pupils that they were similar, but we felt from their body language and some comments that they were not convinced. Another obstacle is the number of cases that must be inducted to make the process obvious and convincing. We have not researched this but normal practice in schools is to have only a limited number of examples. In this position, the teacher is compelled to short-circuit the induction process, and to spell out the historical conclusion, so failing to involve the pupils in the inductive process. This is counter to the principles adopted by HIPST, where the historical context is intended to be the source from which pupils can make authentic enquiry. As an alternative, we can use pedagogical secondary source methods such as card sorts where the cards contain historically derived information, while the pupils add to the card information through personal practical work. The process of induction is preserved, at the cost of personal acquisition of the whole of the data. This needs to be explored separately in a subsequent enquiry, not as part of HIPST.
10. Methods and media for learning	The methods used in this teaching module are varied, and integrated, although all pointing to the central position of practical and experimental work as a major tool in exploring meaning. The module uses practical work to establish the behaviour of a class of materials in order to understand the nature of that class. i.e. the concept of acidity. However, the challenge is that none of the acids has the behaviour of the ideal acid, so that the process of induction has to overcome these imperfections. Making explicit this process, usually carried out intuitively by the pupils, is part of teaching them about the inductive process. A second pedagogical method was the use of simulated newspapers. While real newspapers have been used in science education, simulated newspapers have been scarcely used, even in history lessons. The newspapers, of which an example is given in an appendix, comprised secondary historical evidence (simplified by the editor), simplified philosophical explanations, short play scripts to demonstrate processes of argumentation and dialogue that might have taken place, and reports of lesson activity, conversations (made anonymous), puzzles, and challenges. Discussion was a central element of the pedagogical process.
11. Pedagogical skills	• Discussions: inclusive discussions are common in English classrooms. However, good whole-class discussions may have interference

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from poor behaviour. A good article that can help to frame good discussions is at http://diversity.arizona.edu/Documents/Creating_Inclusive_Learning_Environments.pdf . Alternatively, well-structured group discussions may be more inclusive. Clear roles for group members need to be established through agreed ground rules.

- Role play: good role play has clear direction concerning the roles, and sufficient time for the participants to think about their roles. A danger is that participants identify too much with their role. The teacher needs to give them time and space to step out of role, perhaps by an individual reflection activity about the other roles.
- Teacher-generated plays. These were included in the student newspapers to provide evidence for the kind of discussions that were taking place at the time. Writing them at an appropriate literacy level was a challenge. One teacher-generated play on Boyle's use of indicators was used to significant success. A second play to discuss alternative views about acids, using a Galileo discourse style involving to attendees as one of Boyle's lectures, and a listening pie-seller, generated some valuable discussion.
- At the end of the lesson on Ideal Acids, they were shown a box containing a bottle of Ideal Acid. Opening the box, they saw the box was empty, because the Ideal Acid only exists in the imagination, it is not real. For homework, they created a box of their own with their learning about acids and Ideal Acid on the outside. The details of the boxes are being analysed.
- We were interested in whether the students could construct a chronology of discoveries about acids. This was done by a card sort where the random cards had to be placed in chronological order through discussion in small groups. This was not based on memory but on rational discussion. Most groups were able to do this.
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<td>12. Research evidence</td>
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The research evidence was collected by means of a word association test, student note-books, and field notes.
The word cloud below results from asking one class to record all the words they associated with 'acid'. The responses ranged from 5 to 37 words. The text from all students was pasted into Wordle which outputs a word cloud, with the font size representing the frequency of use of the word. The word cloud demonstrates the largely negative view of 'acid' by this group of students. The collection of words was made at the start of the module, and took 5 minutes.

The students made a box, on which were written details of their learning about the Ideal Acid. This showed that the great majority understood the features of the ideal acid. The data is still being analysed but preliminary analysis suggests that a minority understood the nature of idealisation.
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	The students carried out a reflection lesson. This comprised a whole class play about the nature of Ideal Acid, a card sort on the chronology of acid discoveries carried out in small groups, and a card sort about idealisation. The quality of the conversation demonstrated deep engagement on behalf of all the students. This data is being further analysed.
13. Author's reflections	There were a number of factors that influenced the study. Some of these were inevitable and out of control of the researcher, while others could be changed. • In the middle of the project, for personal reasons, the researcher was unable to meet with teachers for a considerable time to design the Case Studies. This led to delays in design but also to a method where the researcher provided an overall structure that was then modified during trials. Since the teachers had expressed their view that their personal knowledge of HPS was limited, this provided a base for their work, such that the teachers saw this as a strong learning activity for them. In the first place, they claimed that they would simply enact the strategy in their classes but it was clear that local circumstances and their personality led them to adapt the programme. • One teacher was a graduate chemist, and the other was a graduate physicist. Both had been teachers for many years. • The lessons were quite short, 50 minutes with the usual delays in students arriving late from another lesson. This influenced time for discussions and scene-setting, and may have resulted in these sections being too short, in retrospect. Shorter lessons are becoming more common as Head teachers try to squeeze more into the curriculum as a result of government interventions. • The lesson formats were influenced by pedagogical preferences of the two teachers, one taking a more socratic approach of question-answer sessions with the whole class, and the other giving more structured instructions for activity. In both cases, the students were following the lead of the teachers, limiting their own inquiries. • The shortage of time in each lesson, and pressures to complete the work in a short unit, led us to provide extra material in the form student newspapers. While we took every effort to make the reading as simple as possible, it remained a challenge for some of the students. • We were constrained in giving formal tests through lack of time. The NoS questionnaire took up a lot of time in the first lesson. There is great pressure in the National Curriculum to complete units of work, and, perhaps, much less freedom than in other countries in the project. • Dealing with younger students, who may lack maturity and skills to carry out activities required, put lots of pressure on simplifying the ideas.
14. Further user professional development	This is well provided in the associated wiki-site at www.ukhipstacidity.wikispaces.com, as well as the teachers' scholarly reading page reproduced in the appendix.
15. Written resources	*A copy of each of the written resources has been provided as an appendix*

Appendices

Scheme of work for History and Philosophy of Acidity, as a route to establishing concepts of acidity

The Scheme of Work provided below cover learning of acidity from lower secondary school (ages 11-14 in the UK) to pre-university level. Only the first two topics are considered in this module, which is largely phenomenological and operates entirely at the macroscopic representational stages. Nevertheless, the whole scheme is presented here to demonstrate the order of concept flow.

Topic	**History and philosophy**	**Comments**
How do acids behave? Behaviour of acids in solution in respect of indicators, reaction with active metals, neutralisation of bases.	**History:** Indicators (e.g. Boyle and Lemery); Instruments; Boyle paper on elements **Philosophy**: Models and causative nature of explanations.(Lemery's shape of particles) **Syrup of violets** A preparation made from SYRUP and flavoured with the flowers of the VIOLET. Making a syrup of the flowers was probably the most common way of preserving them for use throughout the year, so that it is found in most shops selling APOTHECARY. Since it was believed to have some medicinal properties it may often be noted expressed wholly or partially in Latin as in 'Sir' vyolaru' 1 li di' [Inventories (1624)], and/or heavily abbreviated as in 'S violaru' [Inventories (1573)]. John Houghton indicated that syrup of violets retained the blue colour of its flowers, as well as pointing to a possible adulterant in NEPHRITIC WOOD [Houghton]. Whether it was ever used for this purpose, is not known. It is apparent, judging from valuations, that the quality of this syrup varied, being costed from 2s LB or less [Inventories (1634)], to double that [Inventories (1665)]. This may be explained by the two recipes given in an anonymous Book of Simples. In the first, the violet flowers were infused in boiling water. The liquor was then strained, the sugar added and the whole reheated only sufficiently to dissolve the sugar. In the second, no water was added, but a thick syrup was	**Avoidance of whiggishness:** Classification of materials based on behaviour (macroscopic v sub-microscopic explanations). Novel historical tools to explore phenomena (indicators) **Learner material (in appropriate language):** Terminology; History of indicators; NoS as classification based on regularity; Induction; Regularity Paradigm Biography of Boyle Biography of Lemery **Teacher material (in addition to pupil material):** Causative nature of explanations (a simplified philosophical approach) Modelling Regularity Induction Paradigm and paradigm shift

	obtained by gradually heating alternate layers of the flowers and the sugar [Anon (1908)]. A late edition of Nicholas Culpeper's English Physician' concluded that the syrup 'is of the most use, and of better effect, being taken in some convenient liquor; and if a little juice or syrup of lemons be put to it, or a few drops of the oil of vitriol, it is made thereby the more powerful to cool the heat, and quench the thirst, and giveth to the drink a claret wine colour, and a fine tart relish pleasing the taste' [Culpeper (1792)]. A recipe for syrup of violets was still included in the London Dispensatory of 1746, but it was probably used by then primarily to mask the taste of unpleasant medicines [Pemberton (1746)]. It is the only product of violets still included by that date. OED earliest date of use: 1400-50 under Violet	
Oxo-acids - oxides of non-metals phosphorus and sulphur. Acids as oxygen containers	**History:** Systematisation and terminology (Lavoisier) Morveau paper on phlogiston Lavoisier paper on elements Macquer paper on elements **Philosophy:** Models and causative nature of explanations (all acids contain oxygen, then enshrined in nomenclature). Acids contain an empowering feature (oxygen or acid-maker)	**Avoidance of whiggishness:** history of search for causation, and existence of common phenomena (must mention dates of sulphur and phosphorus discoveries and references) **Learner material (in appropriate language):** Terminology, especially naming of acids with different proportions of oxygen Biography of Lavoisier Biography of Morveau Biography of Macquer **Teacher material (in addition to pupil material):** Dualism to explain nature of acid and base.
Hydracids - dual concepts of acids (oxygen and hydrogen-containing)	**History:** Davy (1810), and Davy (1810) and (Davy (1810) Wikipedia) **Philosophy:** paradigm shift in the face of conflicting evidence (can the existing paradigm explain all of the data).	**Avoidance of whiggishness:** lack of clarity about the nature of an element, and of methods to identify elemental nature of a substance. **Learner material (in appropriate**

	Ideas coexisting in the face of lack of resolution.	**language):** Davy biography Tests for power of theories **Teacher material (in addition to pupil material):** Paper on why the two paradigms existed in parallel?
The role of water - distinguishing between the solute and the solution.	**History:** Davy (1815), and Davy (1815) and (Davy (1815) Wikipedia). Davy discovery of chlorine. Absence of instruments (to await Arrhenius) **Philosophy:**	**Avoidance of whiggishness:** Davy and Arrhenius were focused on the solute alone. It took more precise measurements (and better instruments) to investigate the role of the solvent in the 1920s **Learner material (in appropriate language):** Concept of element Instruments in chemistry **Teacher material (in addition to pupil material):** Paper on why the solvent role was neglected?
Ion formation (Arrhenius, 1884). Potential for repeating his experiments but getting at similar data. Perhaps could use Kohlrausch's data if more easily available.	**History:** Arrhenius (Wikipedia) Arrhenius paper on dissolving Sorenson paper on pH Negative pH and some other ideas discussed by an African Kohlrausch's work (variously reported as around1875-79: he was born in 1840) on instruments for conductance in solution He used a telephone for detecting alternating current (Wheatstone Bridge and an induction coil for AC) Kohlrausch's Bridge and Kohlrausch from Wikipedia His paper scanned in with work from Faraday and Hittorf showing their instruments are here. Pictures of Kohlrausch's Bridge He objected to a street car line outside to get greater precision	**Avoidance of whiggishness:** Development and availability of Kohlrausch Bridge as a precursor. **Learner material (in appropriate language):** Terminology (ions, names of electrodes) Biography of Arrhenius Biography of Sorenson Biography of Kohlrausch **Teacher material (in addition to pupil material):**

	Hitchcock's paper (1923) using the Kohlrausch Bridge Stubb's paper on conductance of carbon dioxide solutions **Philosophy:** Cause and effect explanations Quantitative work as an indicator of explanatory power	Instruments used by Arrhenius and his challenges in measuring conductivity while avoiding polarisation
Proton transfer (Brønsted-Lowry, 1923)	**History:** Brønsted biography) Brønsted description (1923) Lowry Described (1923) ChemTeam's report of Lowry's work Wikipedia report **Philosophy:** A short discussion of paradigm shift	**Avoidance of whiggishness:** Focus on need for non-aqueous systems, including ability to work with anhydrous liquid ammonia under pressure in titrations. **Learner material (in appropriate language):** Non-aqueous solvents Biography of Brønsted Biography of Lowry **Teacher material (in addition to pupil material):** Research on learning B-L theory here
Lewis acids (1923)	**History:** Lewis acid from Wikipedia **Philosophy:** A theory that did not give rise to a paradigm shift! Needs a paper on why not. Linking with another theory (Lewis electron pair theory of 1916) Usefulness of too broad a theory of acids.	**Avoidance of whiggishness:** Focus on significance of electron-pair model and Lewis' team desire to apply to a range of chemical explanations. **Learner material (in appropriate language):** Biography of Lewis Lewis electron pair theory **Teacher material (in addition to pupil material):** Uses of Lewis acids How to choose an appropriate theory to study for different topics

Other theories - these are included for completeness or for extension work	**History:** Solvent theory (increasing solvonium cations in an autoionising solvent) Ascribed to Edward Franklin in 1905 Liebig definition, 1838, (hydrogen replaced by metal) Usanovic (acid accepts negative species) Lux-Flood definition (acid is oxide acceptor) Pearson (hard and soft acids) **Philosophy:** Theories that did not give rise to paradigm shifts! Needs a paper on why not.	**Avoidance of whiggishness:** Focus on availability of non-aqueous solvents and need to develop an explanation for reactions in these systems **Learner material (in appropriate language):** Biography of Edward Franklin Biography of Liebig Biography of Usanovic Biography of Lux Biography of Flood Biography of Pearson **Teacher material (in addition to pupil material):** Theories that did not give rise to paradigm shifts!

Lesson plans in outline

Topic

Area 1
What is an acid?
How do acids behave? Behaviour of acids in solution in respect of indicators, reaction with active metals, neutralisation of bases.

Lesson 1
Characterising acids and alkalis using indicators
Use dilute solutions of inorganic and organic acids, including fruit acids, for this activity. Indicators can include litmus solution, fruit teas (make the really concentrated), alcoholic extractions of coloured plant materials (leave petals infusing in ethanol for a couple of weeks). Robert Boyle used syrup of violets - try this.
Lesson plan for indicators
You Tube videos for indicator testing using red cabbage

Lesson 2
Characterising acids using sodium carbonate and calcium carbonate (marble)
Watch for the fizz if an acid solution is used. calcium carbonate is not so good here because it gets coated with the insoluble salt very quickly, preventing further reaction.
Carbonate tests for acids

Lesson 3
Characterising acids using reactive metals
Magnesium and zinc are useful metals to use. Watch for the fizz. Some of the reactions may be every rapid, with the solution getting very warm. Some may be very slow, especially with zinc foil.
Metal acid reactions

Concept

This section is about being clear what an acid is. **Safety**: acids are potentially dangerous, corroding skin and clothing. Alkalis also react with skin. Goggles at least must be worn.

Lesson 1 is a re-enactment of Boyle's use of indicators.

Lesson 2 is a part use of acids for detecting carbonates in mining in medieval times.

Lesson 3 is normally taught as a reaction of acids but can be seen as a method of characterising an acidic solution.

History

History:
Indicators (e.g. Boyle and Lemery);
Information on litmus
Article about red cabbage indicator, some parts very tough going.
'How stuff works' article on red cabbage
Wikipedia violets

Boyle paper on elements
Joe Peatrovsky's history of acidity
Another history of acids and alkalis

This history site gives recipes for various syrups of plant materials including syrup of violets said to be used by Robert Boyle in 1665 as a practical indicator. Boyle claimed to be the first to note that alkalis turned syrup of violets to green in his book 'The Experimental History of Colours'. Of course, cloth dyers also knew a great deal about colour changes of plant indicators and used this knowledge in their work. Syrup of violets had a long medicinal history before Boyle used it for indicating an acid.
Ancient medical uses of syrup of violets.
Medieval lead mining
Contents page of German mining in 13th and 14th century

The place of coinage in medieval times is part of the culture of establishing a civilization and of trading within that civilization. This is one of the interactions of society and science/technology.

Extraction of metals is also part of military history as tribes/nations battled for territory and resources and developed weapons to do so.

Philosophy

There are two ways of making sense of concepts. One is induction, which means taking lots of examples and working out what they have in common, or what they are all trying to say. the second is deduction which means saying what the idea is and then looking at examples to see if they fit.

The following examples show deduction in action. Scientists know about the effect of acidity on carbonate rocks, as you do from your practical work. See how they think about deducing this from their general understanding of acids on carbonate rocks.

Carbonate rocks discovered on Mars

New Scientist article on effect of acidity on finding carbonate rocks on Mars

Sodium reacts with four acids
Faraday lectures

Area 2
The magic ingredient in acids
Lesson 4
Characterising acids as oxides of non-metals
Burn some sulphur in oxygen, in a combustion spoon (in a fume cupboard) and shake the new gas formed with water. Test the solution with indicator paper. Some of the non-metals can be very dangerous, or difficult to burn so your teacher may have done this beforehand and dissolved the non-metal oxide in water. You may also have other solutions labelled phosphorus oxide solution, and carbon dioxide solution. This picture table may help you to see whether sulphur, phosphorus and carbon are metals or non-metals. (the picture table is full of interesting and highly visual stuff about elements)
Sequence of burning non-metals in oxygen
Lesson 5
Characterising oxides of metals
Burn some metal, in a combustion spoon (in a fume cupboard) and shake the new material with water. Some of the metals can be rather dangerous to use so you your teacher may have done this beforehand and dissolved the metal oxide in water, if the metal oxide is soluble. Test the solutions with indicator paper. If the metal oxide is insoluble in water,

Lesson 4 helps to identify acids as oxides of non-metals.

Lesson 5 has the challenge of induction, plus the challenge that many metal oxides are insoluble in water, so can not make solutions to be tested with indicators. The extra test with acid is an alternative in these cases but is more difficult for young chemists to understand.

Burning non metals
Video burning sulphur
Burning phosphorus
Burning red phosphorus

Burning metals
Video burning sodium
Video burning potassium
Burning lithium
Burning magnesium
YouTube burning magnesium
Burning iron
How hard is it to set fire to a magnesium computer case? Very hard!
Another video of burning

Extraction of metals is also part of machinery development, in the move from wood and stone to stronger materials. This is nowhere more obvious than in the development of the plough.
History of acid-base ideas, rather tough going in parts.
Antiquity: Article on French Alps mining
Polish carbonate rocks in medieval times
History of etching

Looking for the magic ingredient that is the cause of acidity would not have been strange in medieval times. Alchemy was an occult activity and chemistry in the 16th and 17th centuries was not far from that link to the past.
Firstly, Lavoisier was a great proponent of the idea that oxygen was the magic constituent. Secondly, Liebig proposed that hydrogen was the major ingredient. they are both coming from the same viewpoint, that is, the idea that there is something in all acids that gives them its character.

Looking for a cause that would have a clear effect is part of the nature of explaining. Searching for a cause in this way is a philosophical activity. The debate over phlogiston did not take long. Johann Joachim Becher in 1667 created the idea. Mikhail Lomonosov, in 1753, weighed the metal before and after burning and concluded that phlogiston was not a helpful idea, especially when it did not change its mass when air was excluded, contrary to Robert Boyle's prediction. Joseph Black's student Daniel Rutherford discovered nitrogen in 1772. Antoine-Laurent Lavoisier's painstaking work confirmed Lomonosov's results. However, it is good to note that Lavoisier's results were turned down for publication and that he had to establish his own journal to get them into print!

The characterisation process uses the philosophical process of induction, i.e. collecting lots of examples to see what they have in common.

see if it can react with dilute hydrochloric acid solution (**safety** - the acid solution is corrosive, so wear goggles and take care).
Comparing metals and non-metals

magnesium

Scholarly reading for teachers relating to acidity.

The readings below are classified into aspects of a teacher's subject knowledge underpinning successful teaching of acidity. Some are quite challenging to read and understand. However, no one said it was easy to be a good teacher! There is no test to check your own knowledge! You have to make up your own mind if you are ready to try some other reading.

Chemicals as instruments - Hyle article

Acidity is a fundamental, yet complex, topic in chemistry. The articles below will give you overviews from different standpoints on ways of explaining acidity.
Wikipedia article on acidity: focuses on maths and Bronsted Lowry model
High school article on acidity: focuses on maths and Bronsted-Lowry model
Beginning students article on acidity: shows some of the boundary thinking about acids but moves to Arrenius with chemical formulae
Images of pH scales

The papers below provide information about children's ideas in chemistry
Oklahoma article on children's ideas about acids
Understanding of acid-base concept by using conceptual change approach
Exploring mental models and causes of student's misconceptions in acids and bases
Michal Dreschler Models in chemistry education: A study of teaching and learning acids and bases in Swedish upper secondary schools
Michal Drechsler and Hans-Jürgen Schmidt: Textbooks' and teachers' understanding of acid-base models used in chemistry teaching
Details of a book on misconceptions in chemistry

Here are some articles on ways to represent acidity
Three levels of representation of chemical matter
Hoffman's 1991 paper on chemical representation

Coll and Taylor write about the related topic of chemical bonding.
Richard Coll & Neil Taylor: Mental Models In Chemistry: Senior Chemistry Students' Mental Models Of Chemical Bonding

History of acidity
BBC History of acidity in intermediate language
History of acidity is embedded in this Wikipedia article on chemistry
Main Wikipedia article on acidity
Early Acid Base Theories: Lavoisier and Davy
Mark Lesney A Basic History of Acid - From Aristotle to Arnold
History of acids article
Brief history of pH invention
First pH meter invention
Acid-base history based on blood acidity

Paradigm change
Wikipedia - Paradigm Shift
Dictionary definition of paradigm (A set of assumptions, concepts, values, and practices that constitutes a way of viewing reality for the community that shares them, especially in an intellectual discipline.)
Interpretation of Kuhn's view of paradigm shift
Wikipedia on paradigm, especially scientific Thinking inside the box is normal science: thinking outside the box represents, possibly, a paradigm shift!

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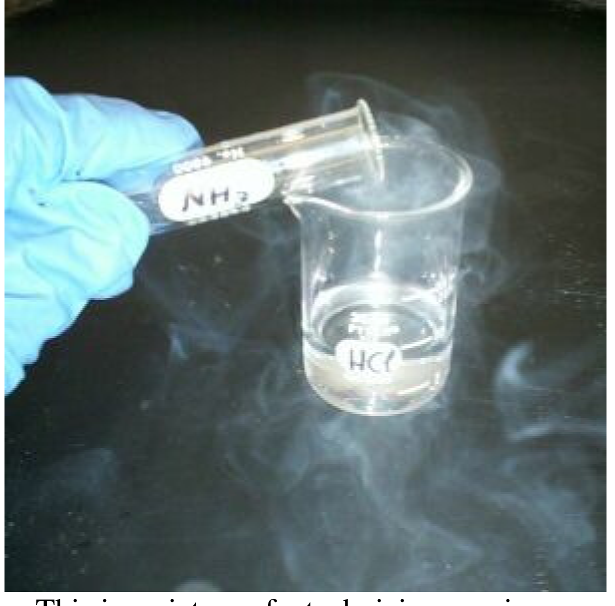
Acidity



This is a picture of a technician pouring concentrated ammonia solution into concentrated hydrochloric acid. Do not try this at home!

History of the word acid: it comes from an old word ak- 'to be pointed or be sharp' (from encyclopedia.com). I have been told that it came from the Greek word 'acme' meaning 'point'. We know that some safe acids feel as though they are pricking the tongue.

History of acids

Many inventions and discoveries we made by Muslims in Medieval times in the Middle East (see http://wapedia.mobi/en/Inventions_in_medieval_Islam#1.

Symbols for common acids were created in medieval times, although the names were Latin. See http://www.sharpe-designs.com/alchemy%20and%20herbalist%20symbols%20scroll.htm for a picture of the scroll with the symbols.

Medieval scholars knew about acids and alkalis from their different behaviour. They had not thought much about what might be in the acids to make them behave the way they do.

Jabir ibn Hayyan around 800 AD made hydrochloric, nitric, sulphuric, citric and other acids. He invented the glass retort for distilling chemicals on a furnace, such as alcohol. Jabir has been called the father of modern chemistry (see http://www.ummah.net/history/scholars/HAIYAN.html). He is known better for his views about chemistry than for his religion.

A glass retort

Nicholas Lémery (November 17, 1645 - June 19, 1715) French chemist, was born at Rouen who was one of the first to develop theories on acid-base chemistry. He studied as a pharmacist.

Nicholas thought that acid particles had little points on then, to prick the tongue. He also thought (in 1680) that alkalis had little holes in them for the acid points. This neutralised both the acid and alkali effects. He swapped religions when he had to flee France to England as a Protestant Calvinist in 1683 He then became a Catholic in 1686 to return to France to open a pharmacy shop. Now we see the influence of religion at that time and how people behaved.

Nicolas Lemery (from Wikipedia)

Wilson’s view of acids (1856)
George Wilson wrote a book about chemistry in 1856! At that time, chemists were thinking about acids and what was in them that made them an acid.
George knew that acids tasted sharp, and turned some vegetable dyes red, orange or yellow if dissolved in water. At that time, chemists were still trying to make sense of dividing acids into two types.

Oxoacids: George’s fellow chemists had burned sulphur, phosphorus and carbon in a gas called oxygen. Antione Lavoisier was a French chemist who lived in Paris and had his head cut off by the guillotine in 1794. Lavoisier invented a new naming system for chemicals. He called the new chemicals: acide sulphurique, acide phosphorique, and acide charbonique. George called them sulphuric acid, phosphoric acid, and carbonic acid. You can see how he got these names from the French. Today, we called these chemicals: sulphur trioxide, phosphorus pentoxide, and carbon dioxide. Can you see how they tell us the number of oxygen atoms? What do you think ‘pent’ means?

Although the chemists only used these oxides as acids in water, they only thought at first that the water was an easy way to handle these gases.

Hydracids: George also knew about some other acids, such as hydrochloric acid, with no oxygen in them. He called these hydracids, so that they would not be confused with the oxoacids.

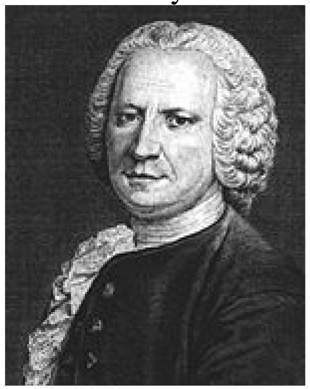
George knew that water was made of hydrogen and oxygen, H_2O. George said that when the oxoacids dissolved in water, the hydrogen from the water became part of the acid. He made a chemical equation:

$$SO_3 + H_2O \rightarrow H_2SO_4$$

George said that the new chemical, H_2SO_4, was really the acid as it now had hydrogen in it.

Meaning of alkali
This is a late 14th century word from the Arabic al-qili "the ashes" (of saltwort), from qala "to roast in a pan". The start of the word (al) tells us it is from Arabic ideas.

Guillaume François Rouelle (1703-1770) was a French chemist and pharmacist. In 1754 he introduced the idea of a base into chemistry, as a substance which reacts with an acid to make a salt by neutralisation.



Making sense of acidity
There is a lot of history in this newspaper. Some of it may be tough to understand but you can work at it. Perhaps, even more importantly, how the ideas were taken up by scientists is part of How Science Works.

Sometimes, we can understand How Science Works better by looking at history. Often the information is clearer.

What science actually is may be called The Nature of Science. Thinking about acids can give some idea of what this means.

One of the ways that scientists try to understand the world is to classify, or group, what they see. It can take a lot of playing around with grouping to get one that helps scientists to predict what might happen in future experiments. Sometimes, they create a theory.

What is a scientific theory?

A scientific theory is created to *explain* something that can be observed. There are some rules about good scientific theories. Here are some of them:

1. A good theory explains much as possible of the information that has been collected (*data*), including that from other scientists.
2. A good theory can help scientists design new investigations. These theories are called fertile. The good theory can explain the new data.
3. A good theory usually works well with other theories that scientists already have.
4. A good theory can explain measured data with mathematics. These kinds of theories are the most respected by scientists.
5. A good theory has the simplest explanation, with the least number of ideas.
6. A good theory has the smallest number of objects in it.
7. A good theory does not have unexpected faults, or use ideas such as fairies or elves to explain where the theory does not work.
8. A theory is helpful in finding the best explanation so far. Some theories are still rather uncertain, like global warming, while still being the best we can find. Other theories, such as atoms and molecules, have been around for a very long time and are much more certain.
9. It is true that all theories can change. In practice, most scientific theories do not change much. We call these theories *stable*. A few scientific theories are still being created. Scientists may disagree in public about them. We call these theories *provisional*.
10. Some people say ‘this bit of science is only a theory’. Science is not only about theories but is about collecting the best data possible. Science is also about designing new tools for measuring data. Science is also about designing new experiments. This is one of the creative bits about science.

How does this work for acids?

1. Scientists collected *observed* data about how acids behave.
2. Scientists worked out how the *ideal* acid might behave by thinking about all the real acids. This process is called *induction*.
3. The ideal acid is not real. It only exists in our imagination.
4. Scientists used the ideal acid thought to *dedu*ce what a new real acid might do. They might check whether the real acid does this. This is also checking whether the idea of an *ideal acid* is any good at explaining.
5. Scientists will continue to use the idea of an *ideal acid* until it stops working well at explaining what they observe or measure.