Case Study Exchange Format – HIPST
Instruments 1

Details of section	Guidance
1. Title	Temperature – what can we find out when we measure it? Key words: temperature, thermometry, measurement, instrumentation, scale, calibration, construction, particle
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3. Abstract	Temperature was a rather elusive concept until it was measured in history. The development of instruments for quantitative measurement was vital for characterising the concept, for explaining human sensations of hot and cold, for providing ways of exploring a range of temperatures greater than that of direct human experience, and for exploring the nature of the measuring instruments themselves. Temperature is a basic concept in junior high school (lower secondary school) science. Through practical activities, it provides a tool for learners to start to distinguish between temperature and heat, largely through the effects on different phases of water at different temperatures. In many countries, including the UK, learners explore particle explanations for change in junior high school, and this activity is intended to build on that experience, and to consolidate it. Traditionally, learners would be presented with traditional liquid-in-glass thermometers with very little idea of how it worked but an instrumental. The approach in this Case Study is to start from the construction of a particular thermometer, one of the first types in history, a gas thermometer. It is also important to give learners personal practical experience, so the choice here of equipment is made to ensure that most schools will have the relevant equipment. It differs from a more common approach based on expansion of liquids for more fundamental reasons. The first is that liquid expansion with increasing gas temperature is much more difficult using particle models to explain than increasing gas pressure. There are serious conflicts with the notion of liquid particles moving faster and their motion being curtailed by being in a condensed phase and this does not apply to a gas. Secondly, it is easy to experience increased pressure by its effect on the skin as a finger is placed over the end of the tube leading from the gas container. The activity is relevant to lower secondary school science, and for all abilities. In terms of history, gas pressure was easier to measure using relatively crude glass tubing since only height difference in a manometer is being measured. Liquid expansion requires much more uniform bore tubing, demonstrating the effect of precision glass making on temperature measurement. Philosophical considerations include the impact of measurement in establishing scientific concepts, and ideas about standardisation, calibration and extending instrument limits of measurement.
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. This Case Study has chosen a topic that is on the edge of traditional chemistry, temperature, because it is amenable to a strongly descriptive approach and has a significant historical literature to underpin its development. It is also very closely linked to existing theoretical considerations in junior level chemistry, such as the Particle Theory. The topic of temperature is fascinating because it begins with an unclear understanding by historical scientists about its nature, and about how to measure it. This parallels the position of the 11 year old students in the pilot programme. The historical search for a suitable measurement is inextricably bound up with creating instruments to do the measuring, and the lack of clarity about what was being measured. The nature of measurement itself, and its purposes, is at the heart of this topic. It is perplexing that scientists might search for a way of measuring something whose very nature was elusive. Ideas such as standardising, calibrating, sensitivity, and extending measurement ranges had to be discussed and solved by the community of scientists over a period of history. It was only later, when the nature of heat was explored, and its measurement was created, that confusion between temperature and heat became significant, and these were largely in the domain of thermodynamics which is not the focus of the young learners in this study. The topic of temperature is also significant because it epitomises the distinction between purely relative properties and absolute ones. Temperature measurement existed for a long time before this distinction was resolved by scientists. Temperature measurement is a significant part of culture, most obviously concerned with body temperature and weather in everyday life. In the first case, various thermometers were constructed to increase sensitivity to detect the relatively small changes that would indicate health or sickness. Measuring atmospheric temperature demanded comparability, as well as sensitivity, tied up with reliability. These notions are fundamental to understanding the process of measurement and the nature of measurement. This makes temperature measurement a good topic to engage learners with the self (body temperature) and the world around them (weather). Later, they will have a clearer understanding of the contribution of temperature measurements to climate change. Temperature measurement was an international exercise, as exemplified by Gmelin's Siberian expedition on behalf of Catherine the Great, which forms part of the unit of work. Gmelin's use of The Royal Society's thermometers suggests strong international scientific collaborations in a politically turbulent European society. Such an early example can be used as a foundation for work on citizenship. It is also important to note that the instigator of this expedition was a woman, which was not so common at that time. Finally, in this section, 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.
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*

	• Temperature • Thermal expansion *Processes* • Measurement of temperature using different kinds of thermometers • Exploration of ideas validity, reliability, standardisation, calibration, sensitivity • Instrument design • Exploration of boiling point of water in different containers and at different points *History of science* • Development of the liquid-in-glass thermometer • Exploration of steam point as a fixed point • Development the gas thermometer • Scientific expedition to Siberia *Nature of Science* • Why do scientists measure? • Specification of standardisation and calibration in instrument production • Nature of uncertainty in measurement **Expected outcomes of learning** *Concepts* • Know that temperature is the measurement of the intensity of heat • Know that temperature of measured by the thermal expansion of liquids in a glass tube or by the increase of the pressure of a gas in container *Processes* • How to measure temperature using different kinds of thermometers • How to explore of ideas of validity, reliability, standardisation, calibration, sensitivity in the context of temperature • How instrument design of thermometers was carried out • Exploration of boiling point of water in different containers and at different points *Nature of science* • Why do scientists measure? • Specification of standardisation and calibration in instrument production • Nature of uncertainty in measurement *History of science* • Know the history of the development of the liquid-in-glass thermometer • Know about the history of exploration of steam point as a fixed point, e.g. by scientists at The Royal Society • Know the history of the development the gas thermometer • Know about Gmelin's scientific expedition to Siberia for Catherine the Great *Links to formal science content* • Measurement of temperature

	• Particle models for behaviour of solids, liquids and gases *Expected effects on student interest and motivation* • Expected that students would engage with some deep questions, such as whether the fixed stem point is really fixed. The evidence from the practical work is that the majority did, although many did not in these trials • Expected that the students would engage in the historical Gmelin story, which most did, and some were sufficiently motivated to produce their own play scripts • Expected that the students would engage with the newspaper accounts of the history. We suspect that this was not a successful part of the project, partly because of the lack of literacy skills *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, but this was fairly limited.
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. *Historical story* General notions of degrees of hotness and cold were known in antiquity, and Galileo had created his thermoscopes in 1591, followed by a water thermometer in 1593, when sufficiently uniform bore glass tubing was crafted by glass artisans. In 1643, Torricelli invented the mercury barometer, paving the way for Ferdinand II to create the first sealed thermometer in 1654. In 1699, Amontons published his early idea of absolute zero, almost at the same time he was working on the constant volume gas thermometer (1702). Very soon afterwards, in 1709, the alcohol thermometer was invented by Fahrenheit, and then in 1710 Reaumur develops his first thermometer. This flurry of inventions at the start of the eighteenth century continued when, in 1714 Fahrenheit invents the mercury thermometer, and then Celsius at about the same time. Standardising the fixed points took some time, with even the Royal Society establishing a committee in 1776 to study how to specify conditions that all could agree on. Many scientists at this time (e.g de Luc) also investigated having different liquids in the thermometer, and came across the idea of uneven expansion of liquids, although they had little idea of how to quantify it. This challenged their notion of a valid thermometer scale, since it was impossible to determine the extent of the unevenness. Extension of the scale way beyond the ice point and steam point was fraught with the problems of the thermometric liquid boiling or freezing, or the glass melting leading to destruction of the thermometer. Wedgwood was particularly interested in the temperatures in his potter kilns, and resorted to an empirical method based on the contraction of what he thought were reliable rectangles of clay. Nevertheless, he was unable to bridge the gap between the upper practical temperature of a glass thermometer, and the lowest temperature in his kiln. This meant he was unable to compare the two scales. Eventually, it turned out that his pieces of clay were not standard after all! The matter hinged on the practicalities of working with high melting point metals, such as tungsten, and when this was solved, around 1800 by various methods such as expansion of metals and pryometry, and by using a constant volume gas thermometer made of tungsten, the scale could be extended upwards. Modern accounts of the constant volume gas thermometer are at: http://www.brighthub.com/engineering/mechanical/articles/26627.aspx http://video.google.com/videoplay?docid=7496632718761782419# Using 'real' thermometers, scientists investigated the relationship between the temperature of a body and the light it emits. This relationship, in its exact form known as Stefan's law (see, for example, http://www.drchaos.net/drchaos/Whit/Lab_Manual/node6.html) is now used to construct instruments to measure very high temperatures.

8. Philosophical background, including the Nature of Science	*Philosophy story* As we have seen, it is fairly straightforward to construct the history of thermometry. The philosophy, or what is temperature, is not so obvious, as we found out when we asked 50 science graduates learning to be teachers. They were largely phenomenological in their approach, and were not too different from the 150 11-year old students we asked. Apart from suggesting it was hotness or cold, most could not get any further. Some of the graduate physicists suggested that temperature was related to the speed (velocity) of particles in a material. None had the idea that this might only apply to gases, and in particular, an ideal gas if we are being careful. Temperature is a rather unusual concept, not being directly defined by the three base ideas of mass, distance and time. This makes it rather elusice. Chang (2004) gives a good account of the philosophical challenges of temperature. I will summarise his ideas below: • The quest for fixed points, and keeping them fixed so that standardisation can take place. Apart from the effect of pressure, water can boil at different temperatures depending on the container, and where the thermometer is placed. Water without air in it has a different boiling point so entirely pure water is not a good starting point. • Do different liquids in liquid-in-glass thermometers give a 'true' value, or even the same value? How is it possible to check whether the liquid expands evenly with temperature when we only have 'real' thermometers whose expansion properties are unknown? • How can we measure temperature when thermometers melt and freeze? • Is it possible to find an absolute temperature, which is independent of thermometers? Suffice to say that scientists have found an answer to the last question but it only applied to an ideal gas engine. Their quest to find a good-enough real-gas engine where its imperfections are well known has been successful. Chang H (2004) *Inventing temperature: Measurement and scientific progress* Oxford University Press, Oxford The scheme of work, which is attached to this Case Study, has focused on the first philosophical point only, through a partial recreation of the early search for a valid and reliable thermometer.
9. Obstacles to teaching and learning	***Obstacles to teaching and learning*** Harries (1981) highlighted confusion about meanings of heat, heat flow and heat capacity, referring to the underlying notion of heat as a substance. Hewson and Hamlyn (1984) pointed out the embedded ideas of heat as a substance in our terminology. Ericksen (1977) also noted this point. Engel Clough & Driver (1985) mention that pupils also think of 'cold' as a substance. They say that pupils think of cold and hot as different substances, rather than as apart of a continuum. Watts & Gilbert (1985) found 7 alternative children's ideas: • Conspicuous heat where heat is there only when obvious • Dynamic heat, associated with movement • Motile heat, which spreads out • Normal heat, for body temperature • Product heat, manufactured by a process • Standard heat, heat is above freezing and cold is below freezing • Regional heat, where heat is in one area Engel Clough and Driver (1985) see pupils as able to describe heat (it rises, hot things expand) but unable to offer what they see as causal explanation. Tiberghien (1983) reported that heat is hot, temperature is heat, and temperature is a way of measuring heat. Driver & Russell (1982)

found confusion about what might happen if two samples of water at different temperatures were mixed. And this was elaborated by Strauss and Stavy (1982). Stavy and Berkovitz (1980) found similar results. Driver and Russell (1982) discovered that their pupils (between 8 and 14 years old) confused about what might happen to the temperature of an ice water mixture if more ice was added. Appleton (1985) studied 25 Australian children aged 8 – 11 years old who did not recognise a mercury-in-glass thermometer and did not know what it might be used for. They were also poor at estimating temperatures jus above freezing or just below the boiling point of water.

Review: Confusion in this topic is heavily influenced by everyday use of scientific words, and by the lack of explicit teaching of scientific meanings of words, i.e. simply assuming that it is obvious that the pupils will know. A more insidious issue is the holding of the idea that heat is a substance. There is plenty of evidence that practising scientists at all levels have this problem, for example, including heat as a substance in chemical equations. Clearly, the idea is not easy to overcome, and much of our language concerned with heat and heat conduction has implications that heat is a substance. Much of the discussion about heat capacity uses the notion that heat is a substance as its premise. With temperature, we are so used to using the skin as a thermometer (e.g. for testing baby's bath water) that we are oblivious to its inaccuracy, and to it limitations to temperatures not too different to room temperature. Proposals for dealing with these issues are:

- Increase teacher awareness of issues concerning language
- Explicit teaching of terminology, especially where words in common everyday use are encountered
- Devise practical/ experiential activities that focus on one concept only
- Ask learners to explain given incorrect or incomplete explanations
- Ask learners to create explanations and use group critiques
- Devise practical work that challenges one incorrect explanation directly
- Include teacher included discussion of phenomena

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10. Methods and media for learning	See attached sheets
11. Pedagogical skills	• Discussions: inclusive discussions are common in English classrooms. However, good whole-class discussions may have interference 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 s 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. • Play script writing: we used student-generated play scripts to find evidence of understanding historical incidents. The teacher gave a brief account of the incident to the whole class. The students were encouraged to take notes during this and ask questions, and some associated words were written on the board. Approximately 25% of the students completed the plays as a homework exercise. One of the plays was performed for the whole class, taking about 5 minutes. It is important to choose confident and articulate students for this task. • 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. • Inquiry methods: the students investigated taking boiling temperature of water at different points in the boiling water, to recreate de Luc's investigations. They were given a structure, with a few suggestions about where to place the thermometers, but freedom to try other places.
12. Research evidence	The research evidence was collected by means of questionnaire, student note-books, and field notes. The questionnaire showed that the students began with no idea about the history or philosophy of measurement, as explained above. The notebooks and field notes demonstrated that the historical development was well assimilated by the majority, but not all of the students. The philosophy, in terms of the expected learning outcomes, was constrained by the students' modest literacy skills and by some problems in providing equipment, especially the manometers for pressure measurement.
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. In this first topic, I felt that the physicist was more at home with the temperature material, and this may have been the result of more personal subject

	knowledge. In addition, the physicist had an advantage of following the chemist in the sequence of lessons (in another school) and benefited from oral reports of progress, especially in how the activities had been received by the students. As a result of discussions with the second teacher, it was decided that newspapers might be useful and that teacher made more use of them. • 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. • In this topic, the equipment demands for some of the lessons, those using gas thermometers, interfered with the success of the lessons. The problem was the severe shortage of pressure gauges, each school having only two Bourdon gauges. We tried to overcome this by using manometers. The students had studied particle models and we felt confident that they would understand the action of the manometers, in qualitative terms, in measuring pressure. In the event, the technicians found it difficult to build large manometers in both schools, never having done this before. We felt it was well outside their experience, not outside their skills competence given time. This lack of equipment meant that this lesson was not successful. However, the teachers are prepared to try it again next year. • 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. The researchers non-availability, for personal reasons, at the end of this unit menat that it was not closed off as it might have been. • Dealing with younger students, who may lack maturity and skills to carry out activities required, put lots of pressure on simplifying the ideas. This was a success, since we avoided both quantitative aspects, and links with heat, as mentioned above. We feel that it is important to establish the concept of temperature before introducing thermodynamics.
14. Further user professional development	This is well provided in the associated wiki-site at www.ukhipstinstruments.wikispaces.com
15. Written resources	*A copy of each of the written resources has been provided as an appendix*

Appendices

Why do scientists measure?
John Oversby for the UK HIPST project: October 2009

Introduction

At first sight, like many philosophical questions, the answer to the question seems obvious. Measuring is what scientists do, and that is the end of it. We might also say that scientists measure because they want to quantify. The Cambridge Dictionary says quantify means 'to measure or judge the size or amount of something' so it looks like we have just used another word for measure rather than make things clearer! We might say 'to compare'. The Cambridge Dictionary says compare means 'to look for differences or similarities between two or more things'. This does not mean we have to measure. For example, we might say that one ball is red and one is green, and we would not be measuring. We might say that it is to be more accurate and the Dictionary says this means 'exact or correct, without any mistakes'. What started out as a simple question seems to be much more complicated when we look into it. We might, though, start with what kinds of things we measure by looking at the idea of 'properties'.

Properties

If you want to see an expert view of properties, then you can look at the Stanford Encyclopedia of Philosophy which has an article by Chris Swoyer, written in 2000. This is a simplified version for the HIPST project. Properties are attributes or qualities or features or characteristics of things. It seems that all these words mean something that is noticeable that describes a thing! It can be measurable, like the size, or how heavy it is, or how hot it is, or it may not be, such as its smell, or even who it belongs to. The properties we are most interested in can apply to many examples, and not just to one. Some properties can be related. We can say that one thing is larger than another, or that it has a stronger smell, or that it is hotter than it was. These are comparisons and are mainly about differences or similarities. Some of these comparisons are subjective, that is they depend on who is making the comparison. 'Stronger smell' is one of these and different people may make different judgments about whether one thing has a stronger smell than another! These kinds of judgments have a place. In hospital, patients are often asked to give a number from 1 to 10 to describe their pain. What is most important here is to have an idea about how much stress the patient has from the pain, not whether it is exact. In other cases, scientists wish to repeat their experiments, or to repeat the experiments of others. In these cases, it is helpful to have a measurement. In other words, the property measurement is there to solve a scientific problem, of repeating the experiment as close to an exact copy of the first time as possible. Properties, in general, exist to help us solve the problem of describing things, usually by using general properties that many things can have. The concept of properties exist to help in creating explanations.

Measurement

Measurement seems to be used by scientists for a number of purposes:
1. to support faithful replication of work by others;
2. to enable a detailed analysis of data, often based on statistical methods or in testing theoretical ideas;
3. to characterise and elaborate a concept;
4. to provide for further predictions, known as fertility;
5. to examine the smoothness of data, that is, whether there are some otherwise hidden surprises in the collected data;
6. to promote the development of instruments for exploration.

Measurement is beset by various issues such as:
1. Validity, or does the measurement measure what it claims to do?
2. Reliability, or is the measurement repeatable?
3. Precision, or is the error in measurement so small that the value is very close to the actual value?
4. Accuracy, or is the error in the measurement so biased that even an average is some way from the actual value?

In the following description, I will use temperature as my measuring example.

I place validity at the top, since improving the other three are no good if the scientist is not measuring what she claims to be measuring. Some properties, such as temperature, are almost impossible to measure directly. Scientists have to make do with measuring another property that changes with temperature, such as the length of a liquid in a glass tube against a scale, or the pressure of a gas in a container. They face a big question about whether they are really measuring temperature. This question will not be extended in this short article. Measurement of temperature takes some steps:

A. Choose some property that changes when the temperature changes. It is best to choose a property that gives only one value for each temperature. For example, suppose a pressure difference of 2 units was found and measured at two temperatures. On another occasion, another person measuring two units would not know which one of the two temperatures was being measured. Fortunately, the length of a liquid in a glass tube against a scale, or the pressure of a gas in a container are two good properties for this.

B. Choose some method of standardisation. For normal thermometers, scientists have chosen the temperature of a mixture of ice and water as one temperature (fixed point) and the temperature of a mixture of steam and water at standard atmospheric pressure as the other temperature. Scientists have also carefully made clear the conditions so that the standardisation is very well repeatable in different laboratories. For example, many liquid in glass thermometers have '76 mm immersion' engraved on the stem. This means that the thermometer has to be 76 mm inside the ice/water or water/stem mixture to be sure it is reading correctly.

C. Now the thermometer is left at each standardising temperature until it stops changing (do not forget the 76 mm immersion). This might take some time, since different thermometers take different times, and is typically a few minutes for school laboratory thermometers, but can be less than a second for some electronic thermometers. An engraved mark is made on the glass to show the length of the liquid at the fixed point. For a gas thermometer, a mark can be made on the pressure gauge.

D. The space between the two marks is divided into 100 with a scale. The scale can be used when using the thermometer in the future. Strictly, the thermometer is only correct at the two standardising temperatures, but is used at the other ones, too.

Scholarly reading for teachers

Book - Inventing Temperature: Measurement and Scientific Progress (Oxford Studies in the Philosophy of Science) by Hasok Chang.

The Differentiation of Heat and Temperature: An Evaluation of the Effect of Microcomputer Teaching on Students' Misconceptions. Technical Report 87-5.by Marianne Wiser in 1986 Wiser skirts round the issue by focusing on the ways that her students grappled with these two concepts and nowhere gave a clear idea of the meanings of the two concepts, except in the sense of focusing on the difference in being extensive and intensive respectively. Wiser found that her learners could carry out calculations better after using a computer but did not have a better conceptual system. A fascimile of the original paper is at this site.
Can the Study of Thermochemistry Facilitate Students' Differentiation between Heat Energy and Temperature? Mansoor Niaz Journal of Science Education and Technology Volume 15, Numbers 3-4 / October, 2006 concluded that freshmen (20 year old) students, after studying thermodynamics, could not make this distinction clearly, and notes that adolescents have this problem, too.
In Making Sense of Secondary Science, Driver *et al* in 1994 report a range of children's ideas about heat and temperature. Many children think of heat as a fluid (Harris, Hewson & Hamlyn, Erickson, Clough & Driver). Watts & Gilbert interpreted their results in terms of different forms of heat, some of which were described as motion. Tiberghien reported that many adolescents fail to distinguish between heat and temperature (see below for how this continues to be a challenge for adults, too). Some studies (e.g. Driver & Russell in Malaysia and England) use examples of mixing water at different temperatures to explore children's ideas, and come up with multiple confusions about temperature. Appleton found that many Australian children did not know what a mercury-in-glass thermometer was, or what it was used for. He also discovered that they were not so good at estimating temperature. These studies seem to mirror the findings from history discussed below.
Crosland M P (1978) *Gay-Lussac Scientist and Bourgeois* Cambridge University Press, Cambridge is a relatively cheap source of information about this famous scientist.
Frängsmyr T, Heilbron J L & Rider R E (Eds) (1990) *The Quantifying Spirit in the 18th Century* University of California Press, Berkeley
Biography of E H Weber, psychologist studying sensory stimuli, including temperature. Weber created the 3 bowls experiment used in many early science courses to show that using the hand to ascertain temperature can be very misleading. MF Tritsch updated this experiment in 1990.

Historical problem of distinguishing between heat and temperature

Differentiating heat and temperature

Heat can be an elusive characteristic for many. Wikipedia gives a short history of attempts to pin down an explanation of what heat is (here). A common theme in these explanations is the idea of motion (e.g. Abū Rayhān Bīrūnī (11th century), Abd Allah Baydawi (13th century), Avicenna (1253), Bacon (around 1600), Hooke (mid 17th century), Bernoulli (1738), Heat was seen as a fluid or substance for a long time (e.g. Becher, who created the phlogiston idea (17th century), Black (1761), Lavoisier with his caloric theory (1783), Carnot (1824), Clausius (1850)) The idea that heat is a fluid is still entrenched in some of the language we use, such as heat flow and heat capacity. The fluid protagonists did not entirely abandon the idea that heat is motion, since many associated fluid and motion. These ideas still abound today, especially in discussions with scientists becoming teachers who use explanations such as particles vibrating (despite also at the same time exhibiting close-packed touching in solids such as crystalline metals). See also for example in the Wikipedia link (here) 'on a microscopic scale, conduction occurs as hot, rapidly moving or vibrating atoms and molecules interact with neighbouring atoms and molecules, transferring some of their energy (heat) to these neighbouring atoms'. This explanation mixes the idea of hot (a macroscopic feature) with rapidly moving or vibrating atoms (a sub-microscopic feature) and such mis-matches are common, even among some professional scientists. Modern physics at undergraduate level side-steps the issue by involving algebraic functions for both macroscopic features of heat, and for the sub-microscopic explanations, e.g. in both classical and statistical thermodynamics. In these latter cases, concepts are subservient to mathematical treatments.

The Kelvin Library gives access to selections from Kelvin's original library of papers.

Temperature is usually simplistically defined as a measure of hot and cold. 'Japanese has two words for "cold:" samui for coldness in the atmosphere or environment; tsumetai for things which are cold to touch', (from Online Etymology Dictionary, www.etymonline.com). However, 'hot' and 'cold' are difficult concepts to pin down, too. What we can say is that heat can move (as in a fluid?) from hot or cold, so these terms are closely linked with the direction of heat movement. The on-line dictionary, Wiktionary, states that cold means having a low temperature, while hot means having a high temperature, which makes the discussion tautological.

Ma-Naim Chana and Bar Vada in Teaching thermodynamic using the particulate model of matter manaim.doc claims to be able to improve understanding by starting from the sub-microscopic level. However, their paper does confuse translational kinetic with vibrational kinetic energy. Nevertheless, they do acknowledge the need for understanding at the sub-microscopic level.

Such challenges to understanding should provide caution when we try to explain these terms to young, or even older, learners.

Zambrano.pdf Zambrano provides an excellent discussion of the historical work on heat and temperature, and of classroom work (in Colombia) to construct a curriculum to improve teaching and learning.

Kelvin's Kids Club at this web site has some activities to stimulate learning.

Uneven glass expansion giving rise to problems of temperature measurement

(here - Wikipedia)
This article reports how the uneven expansion and cooling of glass when the temperature changes provides an explanation for thermometers giving different readings, even when properly calibrated. A thermometer heated to 100 Celsius and then cooled to 50 Celsius can give up to 0.7 degrees difference in readings when compared with one that has been cooled to 0 Celsius and them warmed to 50 Celsius.

Ideal temperature measurement and invention of Kelvin scale

Wiki - ideal temperature scale
An ideal gas is one whose change in volume (or pressure if the volume is fixed) is linear when temperature changes. This means that a volume of gas can be used to track changes in temperature, and even determine the temperature if calibrated. This thermometer is known as the Ideal Gas Thermometer. It might not be of much help, though, since an ideal gas does not exist! Help is at hand since some real gases behave as though they were ideal under usual atmospheric conditions. Hydrogen is one of these, especially at relatively low pressure.

To measure the temperature of an object, a hydrogen thermometer is placed in contact with the object, until the volume or pressure stops changing. Then the object is at the same temperature as the hydrogen thermometer, which can be found by measuring the gas volume or pressure under the same pressure as it was calibrated. Of course, the gas thermometer will have taken some heat energy from the object, and affected its temperature. Using the smallest possible gas thermometer will make this effect the smallest possible. In any case, we will know the object's temperature when the gas thermometer stops changing!

Other thermometers are calibrated against the gas thermometer, or via thermometers that have been ultimately calibrated using the gas thermometer.

web site here A site concerned with high quality calibration methods is here. International Temperature Scale 1990 on the NPL site.

Modern explanations of heat

Wikipedia explanation of heat This article does try to explain that heat and thermal energy are not the same but in my view (John) fails abysmally. The physicsfront.org explains the difference between heat and temperature This site uses a mixture of animations and experiments to explain the difference.

UK Scheme of Work

The Scheme of Work is related to available National Curricula. In England, these are written in more general terms for 14-16 years old children, compared with 11-14 years old children.

Related to England's Nation Curriculum for Lower Secondary Science (11-14 years old)

The Nature of Science

Pupils should have opportunities to be involved in individual, group and whole class activities. They should be given opportunities to study ideas and theories used in other times to explain natural phenomena and to relate such ideas and theories to present scientific and technological knowledge and understanding.

Education for Mutual Understanding/Cultural Heritage

Pupils should have opportunities to:

• appreciate that scientific methodology is international and that scientific laws transcend national boundaries;

• recognise that scientific knowledge and understanding has been accumulated through the work of people from many cultures and that scientists share an international culture and that no country can develop its science in isolation;

• refer, where appropriate, to the life and work of famous scientists, including Irish scientists, and to the historical development of important ideas in science.

MATERIALS AND THEIR USES

Properties and Uses

Pupils should have opportunities to:

a understand the physical properties of gases and relate these to everyday uses, for example, gases are often stored under pressure because they can be compressed;

Classification

e understand classifications used in chemistry, including

• substances as solids, liquids and gases,

Kinetic Theory

Pupils should have opportunities to:

Particles

a learn that all matter is made up of small particles;

c understand the differences between solids, liquids and gases in terms of the proximity and motion of particles,
d understand changes of state, diffusion and dissolving in terms of simple kinetic theory, including that heat is required to increase the movement and separation of particles and that heat must be supplied to vaporise liquids and melt solids;

PHYSICAL PROCESSES

Energy

Pupils should have opportunities to:

Transfer and Conservation

b understand the distinction between temperature and thermal energy, that is know that temperature is a measure of how hot an object is and is measured in °C, while thermal energy is a measure of how much energy is needed to change the temperature of an object and is measured in joules;

Related to England's National Curriculum in Upper Secondary (14-16 years old)

How science works

Data, evidence, theories and explanations

Pupils should be taught:

a how scientific data can be collected and analysed
b how interpretation of data, using creative thought, provides evidence to test ideas and develop theories
c how explanations of many phenomena can be developed using scientific theories, models and ideas
d that there are some questions that science cannot currently answer, and some that science cannot address.

Scheme of Work in the UK

The scheme of work below is related to existing national curricula e.g. UK National Curriculum.

Temperature

Overview

This activity focuses on the measurement of pressure and its change with temperature, rather than the traditional change in volume. Pressure changes have a certain obviousness of tangible feel about them. This matches Amontons' historical work, but also more easily leads into a sub-microscopic cause and effect explanation. The pressure gauge equipment may not be readily available in schools but an alternative liquid manometer arrangement can easily be set up. The video of the alternative arrangement can then be used for a discussion of the value of instruments.

The experiment consists of attaching a pressure gauge to an otherwise closed flask with air in it. A **video** will be made available for training, and as a resource for students who

Concepts

Macroscopic:

The pressure increases when the air is heated, and can be felt. The use of a gauge introduces instruments. A manometer can be substituted for a mechanical pressure gauge and will provide a useful introduction to instrumentation.

Sub-microscopic:

The push of the particles against an external surface is a powerful explanation here.

Children's Ideas:

Novick & Nussbaum (MSSS 93) found that 13-14 years old children were uncertain about particulate and continuous matter in liquids and, possibly, in gases. Séré (MSSS 152) found that 85% of 11-13 years old could describe squashing air in a ball but 63% referred to the balance of

History

Guillaume, Amontons Biography and another Amontons Biography

Amontons used approximate thermometers but came up with the idea of an absolute zero.

Philosophy

This activity links a macroscopic observation with a causal sub-microscopic explanation. The notion of cause and effect is an important philosophical matter.

Wikipedia here

A second major philosophical area is the relation between measurement and concept development. While there is no intention to pursue this far in this short introduction, the measurement of a thermometric property (expansion of a liquid, or increase in pressure of a gas) and understanding the concept (temperature in this case) was not obviously related in history. This section is as much devoted to developing a teacher's appreciation of this problem at a higher level as showing young learners the problem of determining a fixed

have missed the lesson.	inside and outside pressure. Séré also found these children associating pressure with moving air and not static air.		calibration point using real instruments.
Thermal expansion of fluids (liquids and solids) The next associated lesson is on volume expansion of gases. It parallels Gay-Lussac's historical work. He noted that the thermal expansion of gases is regular and the same for all gases, but that of solids and liquids is not. We can have two activities: a flask fitted with a flexible tube, bubbling into a 100 mL measuring cylinder in a tub of water. Immersing the flask in a tub of warm water will enable the volume change to be measured. The second activity uses a balloon stretched over the mouth of a flask. the flask is placed in a tub of warm water. This activity is not quantitative and provides a good contrast with the (approximately) quantitative prior experiment. The second part focuses on expansion of liquids as a prelude to the next section. Flasks containing coloured water fitted with a stopper and glass tube	**Macroscopic:** Thermal expansion of gases (is regular if measured). Refer to original papers and secondary evidence for other gases. Expansion of liquids is much smaller than for gases and different for different liquids. Refer to original papers and secondary evidence or here for liquids. **Submicroscopic:** The idea of volume change for gases is complex since there is always external air pressure to take into account, and this is not always obvious! **Children's Ideas:** This aspect of conceptual learning has not been well studied. Unpublished work by Oversby and Marks with 17 years old students in Malta suggested that thermal expansion of solids is through particles bumping against each other but no work appears to have been done on thermal expansion of liquids. Oversby (unpublished) also	Gay-Lussac's biography, including his work on expansion of gases with temperature, and referring to the work of Charles, in French. The first paragraph of his memoir concluded with the hope that 'we are perhaps not far removed from the time when we shall be able to submit the bulk of chemical phenomena to calculation' (Crosland MP (1978) *Gay-Lussac Scientist and Bourgeois* p 54 Cambridge University Press, Cambridge) Fenby's paper Heat: Its Measurement from Galileo to Lavoisier	Nature of 'discovery' i.e. who is credited (and in which culture) with the act of discovery? Nature of measurement and primary standards. Determination of the boiling point of water even after allowing for external pressure changes) was a difficult process. This exercise aims to start an understanding of the practical difficulty of calibration of real thermometers, using real instruments.

can be placed into ice cold water (ice and water) and then into water at different temperatures (water baths) to calibrate.	found similar ideas with adult pre-service teacher education students. Challenge to scientists accepted idea of vibrating atoms		
Comparison of different kinds of thermometers. Almost no systematic studies have been carried out with a variety of thermometers, in the light of instruments being used to develop data collection in school science. A lesson plan based on mercury-in-glass and glass clinical thermometers, thermocouples, resistance thermometers, bimetallic strip, and thermistors The mode of operation is described but no indication of precision or accuracy. A wider range is given by Wikipedia An excellent history of temperature and thermometry, written in reasonably accessible language for older teenagers Another published history of thermometry more suitable for teachers. Practical thermometers for measuring body temperatures are explained in the HowStuffWorks site. The explanations seem suitable for older teenagers.	**Macroscopic:** Various macroscopic features (volume, length, resistance, potential difference of a junction between two metals) change with changing temperature and can be used in thermometry. **Submicroscopic:** Explanations of other thermometers tend to be at the macroscopic level. **Children's Ideas:** Appleton (MSSS 140) found, in a small sample, 8-11 years old children did not recognise a thermometer in Australia.	Inventors of different thermometers	The relationship between data and explanation is one to be e

Exploring temperature

Temperature

Your teacher will introduce each lesson. Where the text is blue, it indicates a link. Sometimes this gives more information. Sometimes it links to a page where a word is defined or explained.

Overview	Concepts	History	Philosophy
Lesson 1 The set up activity is a traditional one: Weber's 3 bowl experiment. Place one hand in a bowl of cold water, and the other in a bowl of warm water. Now put both hands in the same bowl of room temperature water. Do you think using the hand is a sound way of assessing temperature? If not, then perhaps we need a more objective way. Take the syringe or flask and put your finger over the end of the attached tube. Now put the flask/syringe into warm water and feel the extra pressure as the air pushes against your finger. What happens to the air particles when the flask/syringe is in the warm water? This next activity focuses on the measurement of pressure and its change with temperature. There are two instruments we use here that early scientists used. Your teacher may use a metal pressure gauge called a Bourdon Gauge. This Wikipedia page on pressure measurement will also give you some background information. Do not worry if you do not understand all of it!	**Macroscopic:** The pressure increases when the air is heated, and can be felt. The use of a pressure gauge introduces an example of an instrument. A U-tube manometer can be used in place of a mechanical pressure gauge and will provide a useful introduction to simplified instrumentation. **Sub-microscopic:** The push of the speeding particles against an the hand is a powerful explanation here.	Early thermometry history from Wikipedia Biographies: Guillaume and Amontons Amontons used approximate thermometers but came up with the idea of an absolute zero. thermometer Galileo used a gas thermometer Wikipedia on gas thermometers Timeline of temperature and pressure measurement technology Explanation of principles of Galileo thermoscope Inventors of thermometers	This activity links an observation with a causal explanation based on particles. Because the particles can not be seen, even with a normal microscope, they are called sub-microscopic. The notion of cause and effect is an important philosophical matter.

Gas thermometer set up video gas thermometer.avi

Another instrument you may use is called a U-tube manometer. Your teacher will explain how to take pressure measurements.

Home made manometer instructions and photographs.

U-tube manometer explanation of how it works (lots of maths)

Chemical Heritage Foundation's Gay-Lussac's and Charles' Law student worksheet

Gay-Lussac's paper translated from the French (Chemical Heritage Foundation)

Lesson 2

Comparison of different kinds of thermometers.

The next associated lesson is on volume expansion of gases. It parallels Gay-Lussac's historical work. He noted that the thermal expansion of gases is regular and the same for all gases, but that of solids and liquids is not.

We can have two activities: a flask fitted with a flexible tube, bubbling into a 100 mL measuring cylinder in a tub of water. Immersing the flask in a tub of warm water will enable the volume change to be measured. The second activity uses a balloon stretched over the mouth of a flask. the flask is placed in a tub of warm water. This activity is not quantitative and provides a good contrast with the (approximately) quantitative prior experiment.

Macroscopic:
Expansion of liquids is much smaller than for gases and different for different liquids.

Submicroscopic:
The idea of volume change for gases is complex since there is always external air pressure to take into account, and this is not always obvious!

Biography Gay-Lussac, including his work on expansion of gases with temperature, and referring to the work of Charles, in French. The first paragraph of his memoir finishes with the hope that 'we are perhaps not far removed from the time when we shall be able to submit the bulk of chemical phenomena to calculation' (from Crosland MP (1978) *Gay-Lussac Scientist and Bourgeois* p 54 Cambridge University Press, Cambridge)

Fenby's paper Heatt: Its Measurement from Galileo to Lavoisier is

Nature of 'discovery' i.e. who is credited (and in which culture) with the act of discovery?

Nature of measurement and primary standards.

Lesson 3

The second part focuses on expansion of liquids as a

prelude to the next section.
Flasks containing coloured water fitted with a stopper and glass tube can be placed into ice cold water (ice and water) and then into water at different temperatures (water baths) to calibrate.
A home-made liquid thermometer can be used as in this example. Thermal expansion of fluids (liquids and gases). The home made thermometer can be checked against a commercial thermometer for accuracy.

A lesson plan based on mercury-in-glass and glass clinical thermometers, thermocouples, resistance thermometers, bimetallic strip, and thermistors, is here. The way it works is described but no indication of precision or accuracy.
A wider range is given by Wikipedia
An excellent history of temperature and thermometry, written in reasonably accessible language for older teenagers.
Another published history of thermometry more suitable for teachers is here.
Practical thermometers for measuring body temperatures are explained in the HowStuffWorks site. The explanations seem suitable for older teenagers.

Macroscopic:
Various properties, such as volume of a gas, liquid or a solid, resistance of a wire, change with changing temperature and can be used in measuring temperature.

Inventors of different thermometers

HIPST First News

Issue no 1

November 2009

Temperature

Welcome to HIPST First News

The HIPST Temperature project now has its own newspaper! All those involved can contribute, so get writing. It will be full of news, ideas and activities, with some puzzles, too.

The HIPST Project is international. Working in 8 European countries, with 11 groups, the Project is working on using History of Science to see how science was developed in the past. In the UK, pupils from schools in the South East and the Midlands are taking part. Some University students are in it, too.

Puzzle No 1

We asked those in HIPST: what is temperature? We also asked some to ask friends and family and to report back. This is what they reported.

Temperature measures hotness and coldness. We decided to test this using three bowls of water. One was very cold, one was hot, and one was lukewarm. Some pupils put their hands in the cold and hot ones for a while. Then they put their two hands in the lukewarm one. Sam takes up the story:
"The cold water was freezing. I could hardly keep my hand in the hot water. When I put my hands in the lukewarm water, it was very strange. The one in the cold water first felt warm. The one in the hot water felt rather cold."

We asked Sam why the water might feel like this.
"Well, the hands can feel differences in temperature. So, to the hand in the cold water first, the lukewarm water feels hot. To the hand in the hot water first, the lukewarm water feels cold."

Sue told us:
"The human body is not so good at measuring temperature, so we need something else more reliable. Reliable means that it will give the same result every time."

Jenny told us we could use thermometers. They were better at measuring temperature reliably.

Daniel Gabriel Fahrenheit
Daniel Gabriel Fahrenheit (1686-1736) was the German physicist who invented the alcohol thermometer in 1709, and the mercury thermometer in 1714. In 1724, he introduced the temperature scale that bears his name - **Fahrenheit Scale**.

Anders Celsius
The Celsius temperature scale is also referred to as the "centigrade" scale. Centigrade means "divided into 100 degrees". The Celsius scale, invented by Swedish Astronomer Anders Celsius (1701-1744), has 100 degrees between the freezing point (0ºC) and boiling point (100ºC) of pure water at sea level air pressure. The term "Celsius" was adopted in 1948 by an international conference on weights and measures.

Anders Celsius was born in Uppsala, Sweden in 1701, where he followed his father as professor of astronomy in 1730. It was there that he built Sweden's first observatory in 1741, the Uppsala Observatory. He was appointed director. He devised the centigrade scale or "Celsius scale" of temperature in 1742.

So, the first thermometers were made around 300 years ago. This year, 2009, is the tercentenary (300 years anniversary) of the alcohol thermometer!

Different scientists chose different scales for their thermometers. Fahrenheit decided that he would see how cold he could get using ice and salt. He called this 0ºF. He chose normal body temperature to be 100ºF. He divided his scale into 100 divisions. On his scale, water froze at 32ºF and water boiled, at normal air pressure, at 212ºF. We also think that Fahrenheit must have had a fever when he chose body temperature to be 100ºF because it should be slightly less.

Puzzle No 2

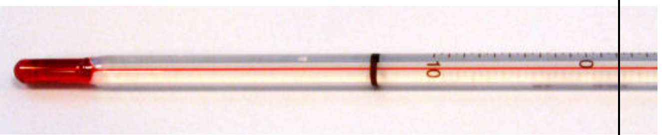
Celsius marked his top temperature as 0ºC and the bottom temperature as 100ºC. See if you can find out why.

HIPST First News
Issue no 2
November 2009

Temperature

Making thermometers

In about 1654 Ferdinando II de' Medici, Grand Duke of Tuscany, made sealed tubes part filled with alcohol, with a bulb and stem, the first modern-style thermometer, depending on the expansion of a liquid, and independent of air pressure.



Alcohol boils at 78 °C, so other liquids are now used for higher temperatures.

Mercury thermometers

Mercury is a useful liquid for thermometers. It boils at a high temperature. It conducts heat very quickly so gets to its final reading fast. It is silvery making it easy to see in the thermometer. When a mercury thermometer is broken, it is sometimes very difficult to collect it from hidden spaces on the floor. It can then evaporate over time. Mercury vapour is very toxic.

Checking reliability

Reliability means getting the same result every time.
Celsius used two fixed points in his scale: the temperature of melting ice and the temperature of boiling water. This wasn't a new idea, since Isaac Newton was already working on something similar. The distinction of Celsius was to use the melting temperature and not the freezing temperature. The experiments for reaching a good calibration of his thermometer lasted for 2 winters. By performing the same experiment over and over again, he discovered that ice always melted at the same calibration mark on the thermometer.

Which way up?

When Celsius decided to use his own temperature scale, he originally defined his scale "upside-down", i.e. he chose to set the boiling point of pure water at 0 °C (212 °F) and the freezing point at 100 °C (32 °F). Today, we think of temperature as ‘intensity of heat’. So, we can increase temperature of a liquid by adding more heat. Celsius called heat ‘caloric’. He also called cold ‘frigoric’. Celsius said there was lost of ‘frigoric’ at the ice point so he said that would be 100. He said that there was little frigoric at the steam point so he called that 0. One year later the Frenchman Jean Pierre Cristin said he would invert the scale with the freezing point at 0 °C (32 °F) and the boiling point at 100 °C (212 °F). He named it Centigrade. Now, we call it Celsius after the inventor.

Fixed points for standardising thermometers

When scientists try to measure something, they set a standard. A standard is a fixed scale that all scientists know and can use reliably.

Scientists worked for a long time to set the temperature standards. They called these fixed points. Eventually, they chose the one used by the most respected scientist of the time. This was Anders Celsius, as it turned out.

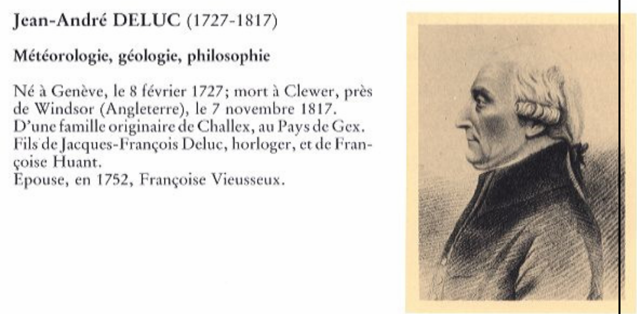
Person	Date	Fixed points
Sanctorius	c 1600	Candle flame and snow
Hooke	1665	Freezing pure water
Eschinardi	1680	Melting ice and boiling water
Halley	1693	Deep caves and boiling spirit
Fahrenheit	c 1720	Ice/water/salt mixture and

		healthy body temperature
Celsius	c 1741	Melting ice and boiling water

c means 'somewhere around'
You can see there many ideas of how to settle the scale for temperature.

The Royal Society
In 1776, the Royal Society of London (a society of leading scientists) appointed a committee of seven men. They had to settle how to standardise temperature. They found that there was disagreement about when the water was actually boiling! Did they count just starting to boil, or bubbling very quickly?

Jean-André De Luc was a member of this committee. The picture below is from encyclopedia.com



De Luc was a Swiss geologist. He spent a lot of time in the Alps (in Switzerland and France) with this brother. He studied the rocks, the plant life. He also studied the weather, or meteorology. He was keen to improve the scientific equipment he used.

De Luc's scientific measurements
He measured the heights of mountains by using a barometer to measure the air pressure! He wrote a lot about thermometers, too. The committee investigated boiling water for a long time. They were not just fussy. They knew that accurate temperature measurement was important for medicine, to find how efficient engines were, and for the study of weather and climate.

They boiled water in glass and metal pots, finding different results for the boiling temperature. They heated the pots from the bottom and the sides. The boiling temperature was higher when the pot was heated from the bottom in some trails but different in others! The results were not so reliable. They also found the temperature was different if the thermometer was deeper in the water. This is why, on the back of liquid thermometers, it often says it should be dipped in (immersed) to a depth of 76mm to give a correct reading. For most school science investigations, the error will be small if the thermometer is dipped in a little, so we are lucky.

Superheating
The committee found that water does not always boil when the temperature reaches the expected boiling point. Then it has to be heated more. This is called superheating. When it starts to boil, it may do this a little violently. This is called bumping. It affects the real reading of the boiling temperature.

Air in the water
De Luc knew that the air dissolved in the water affected the boiling temperature. He decided to shake the water for four weeks to get rid of the water!
'This operation lasted four weeks, during which I hardly put down my flask, except to sleep, to do business in town, and to do things which required both hand. I ate, I read, I wrote, I saw my friends, I took my walks, all the while shaking my water …

The boiling temperature went from 97.5 ºC to 112.2 ºC, just by shaking the water! All of this, just to understand boiling. This was the character of these scientists. They were madly in love with their work. They were driven to finding out exactly what was going on. It turned out that even the Royal Society committee did not get to the end of the story. In 1810, Joseph-Louis Gay-Lussac, a Frenchman, reported on boiling water, measuring to 0.001 ºC, or so he claimed. Even in 1878, the 9th edition of the *Encyclopaedia Britannica* reported: 'It has been stated that the boiling of pure water has not been observed.'

What do we do now?

Today we put the thermometer in water to the correct depth, adjust the pressure of the air round the equipment to 1 atmosphere, and bubble in steam until the temperature stays the same (constant). Then it is at 100 ºC, we say.

Reports from the classes

In this section we will print news of some work from the notebooks.

How does a thermometer work?

The red liquid you see in a thermometer is either mercury or alcohol. What simply happens is the mercury or alcohol expands when heated. In a standard bulb thermometer, this means the liquid will rise (up the tube) as the temperature increases. The liquid (usually mercury or alcohol) in the bulb is free to move in the tube. When the thermometer is touching something like the air, the mercury will grow or shrink. The liquid will stop moving when reaches the same temperature. The marks measure the length of the liquid and the temperature of the air.

Scientists get it wrong! A play

Narrator: Catherine the Great orders scientists to go to Siberia for a measuring expedition.
Gmelin: I'll go but I have no good thermometers! I know, I will get good thermometers from the Royal Society. Theirs have mercury in them and are carefully standardised at the ice point and the steam point.

One month passes until the thermometers arrive.
Gmelin sets off on his 3 month expedition in the middle of winter.

Gmelin: Hi everyone. I'm back. Wow! The lowest temperature was -84.4ºC. We almost froze to death!

50 years pass

Lord Kelvin: Gmelin was wrong. The mercury would have frozen before it got to was -84.4ºC. I wonder what temperature mercury freezes at. We can not go back to Russia because there is a war on. Let's try Ontario in Canada. It is really cold in the winter there.

Scientists get it wrong! A play.

Catherine the Great: Write to Gnelin. I have an idea! The greatest expedition of all time!

Gmelin arrives at the Russian palace

Gmelin: Good day!
Catherine the Great: Hello, Gmelin. I have a job for you. I want you to take an expedition to Siberia and measure the temperature every day.
Gmelin: Well, all right, but I will need two thermometers from the Royal Society.
Catherine the Great I will make sure of it.

After the expedition

Gmelin: Good day Your Majesty. I am back!
Catherine the Great: Wonderful. So what did you find out?
Gmelin: The lowest temperature I recorded was -84.4ºC.
Catherine the Great: Wow! Well done.

50 years later

Thomson: Listen men. I have just realised something. Gmelin was wrong. It was so cold the mercury froze. I will start an expedition to Canada and get it right this time.

Puzzle

Was Gmelin stupid or careless? Remember he was chosen because he was the best scientist at the time. Could his thermometers have been wrong. Send in your thoughts and you could be in the next newspaper.

Scientists tried hard to find the exact freezing point of mercury. It took a lot of effort. The latest value is -38.83 °C. Today, some cold weather scientists use a mixture (alloy) of two metals: mercury and thallium. This has a freezing point of -61.1°C, good enough for most places on earth.

HIPST First News

Issue no 3

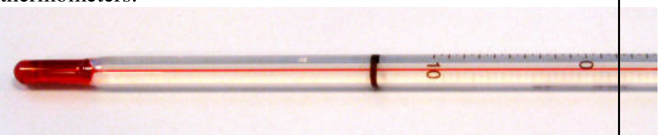
November 2009

Temperature

The gas thermometer

Background

Many thermometers used in school labs are liquid-in-glass thermometers.

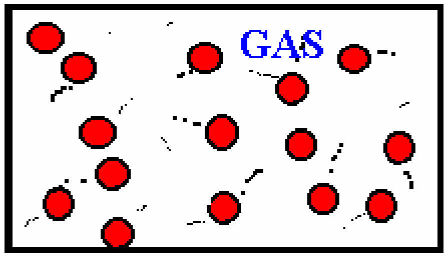


These thermometers have a glass bulb at the bottom, connected to a very narrow glass tube. The thermometer has enough liquid in it to partly fill the narrow tube. As the temperature changes, the liquid shrinks or expands. This makes it move along the glass tube. There is a scale on the glass tube. This is standardised at the ice point and at the steam point so that it is *accurate* at these temperatures. A problem with these thermometers is that they are uneven. They may be correct at the two standardising points, but not so good at those in between, or beyond. This is because the liquid itself expands and shrinks unevenly. The glass also has uneven expansion and shrinkage.

We can say that the thermometer reading is only *valid* at the steam point and at the ice point. *Valid* means that it measures what it claims to measure. In between and beyond, it may well not be so valid. Is there a *valid* thermometer? This would be one that has correct readings in between and beyond, not only at the *fixed points*. It turns out that a practical *valid* thermometer is the constant volume gas thermometer. It was invented in the 17th century, by both Galileo and Santorini.

How does your earlier science learning help?

You have been learning about particle ideas in solids, liquids and gases. For this part, we will only use the idea in gases.



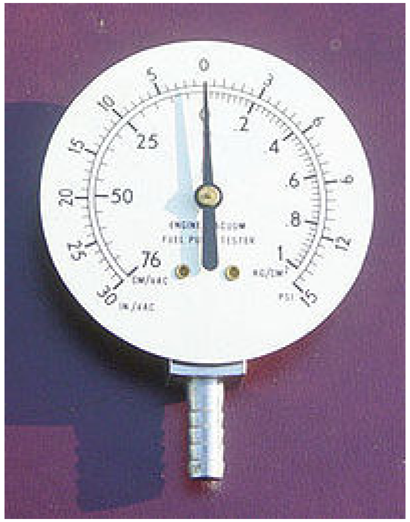
Picture from DocBrown.com

In a gas, the particle model uses the idea that the particles are dashing round at random, hitting each other occasionally but hitting the walls often. The particles are far apart, much further than in the picture above. When the particles hit a surface, they create a pressure. It is this pressure that is used in the gas thermometer.

When the gas gets hotter, the particles move faster. The pressure increases. It seems to scientists now that the pressure change with temperature is even. (This is not quite accurate for air, but scientists know how inaccurate it is and can allow for it.) Because its pressure expands and shrinks evenly as temperature changes, its pressure is a *valid* measure of temperature.

This discovery took scientists a lot of careful measuring to be sure that their ideas were *valid* but now they are very sure. This is the way it often is in science – it takes a lot of evidence to be more convinced.

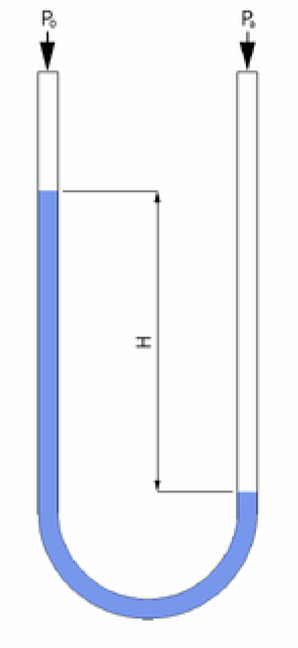
Measuring pressure – a Bourdon Gauge



The Bourdon Gauge works a bit like the party toy that extends when you blow into it. The picture above (from Wikipedia) shows the front scale. There is a tube for connection. It measures the actual pressure. Like all instruments, it has to be standardised, but we usually buy it already standardised. As you can see from the scale, the scale is not so fine, so it only gives rough readings. These would be good enough for school experiments but not for scientists to use.

Manometer

A manometer looks a bit like the picture below, with a liquid in a flexible U tube. Both ends are open. Usually, the liquid levels are the same. This shows that the pressure on both sides, pushing the liquid down, is the same. Normally, this is air pressure. To use, one side is connected to the pressure system. The liquid moves as in the picture if the pressure on the left is lower than on the right. We can say that the particles are pushing less on the left. The manometer only measures differences in air pressure between right and left. If one side is open to the air, then it measures differences from air pressure.



What liquids can be used in a manometer?

Early scientists used mercury in the manometer. Mercury is a very dense liquid – it weighs 13.6 times as much as water, for the same volume. If the pressure on the right is changed to 2 times air pressure, then the difference in the levels will be 760 mm.

In school, you will most likely use coloured water as the liquid. For water, a 1 atmosphere pressure increase on the right would push the level difference to about 12 m, the height of a total of about 20 pupils of 11 years old. This would need a manometer of two storeys high! You will probably use a manometer that is much smaller. This will mean we can only measure small temperature changes.

Can a gas thermometer measure high temperature?

A gas thermometer such as the one you used can not be used higher than about 650 ºC because the glass begins to melt. The picture at the top of this newspaper shows a special metal globe for special uses. If it uses tungsten metal, it can go to nearly 3000 ºC. Tungsten metal is so tough and melts at such a high temperature that it is very difficult to use. This makes tungsten gas thermometers very expensive! We must also believe that it is *validly* measuring temperature if it is so high. Usually, tungsten thermometers use helium gas to avoid such problems.

Some thoughts from scientists' experimental data

A scientist set up a gas thermometer. She placed the air container in melting ice. After 10 minutes, she connected the pressure gauge. It read 1 atmosphere. Then she placed the air container in water with stem bubbling in. It read an increase of one third of an atmosphere (she was using a Bourdon Gauge).

1. What is the pressure increase for an increase of 100 degrees from 0 ºC? One third of an atmosphere.
2. What increase in temperature would give an increase of one atmosphere? 300 degrees.
3. Now imagine she starts from 0 ºC again. What temperature fall would give a pressure decrease of one third of an atmosphere from one atmosphere? 100 degrees. (if the scale is even, which we believe it is.)
4. What temperature fall would make the pressure zero atmosphere, or a fall of 1 atmosphere? 300 degrees. This predicts that at a temperature of about -300 ºC, the pressure will be zero. This is called absolute zero, because the pressure can not be below zero! More accurate measurements show it would be close to -273 ºC. Wow! You can not get colder than that!

Endpiece

This issue has been tough! How about a bit of light relief?

You now know a lot more about temperature and its measurement.

See who can find the weirdest facts about temperature, and the next issue will have a collection of these.

Who can find out how scientists know the temperatures of distant stars? We will publish the best explanation. Give it to your teacher.

HIPST Staff News

Issue no 1

November 2009

Temperature

Welcome to the first issue of the HIPST Staff Newsletter

UK Progress Report

The UK HIPST project is based around some philosophical/ historical themes.

	Science Subject Matter	Philosophical Themes	Historical Theme
Topic 1	Temperature	Measuring: validity, reliability, accuracy, standards.	Technology of thermometers, searching for fixed points. Liquids in glass; gas thermometers. Gmelin's trip.
Topic 2	Acidity	Creating the acid concept. Idealisation. Induction and deduction Paradigm shift	Investigating acid properties and basic properties. Oxygen and hydrogen explanations
Topic 3	Chemical formulae and equations	Paper tools for thinking about chemical processes Equation types	Conservation of matter. Constant proportions. Formulae as explanations Using chemical equations

The HIPST project is now in its final stages. It began in February 2008 and is due to finish in July 2010. Materials will be published from March 2010

Schools interested

1. Yateley School, Hampshire – Nick Johnson and colleagues
2. Calthorpe Park School, Fleet, Hampshire – Evelyn Auld and Mike Wilbrahim
3. Alcester Grammar School, Alcester, Warwickshire – Penny Robotham and colleagues
4. Altwood School, Maidenhead, Berkshire – Lori Bird and colleagues
5. Reading School, Reading, Berkshire – Steve Longstaff and colleagues

University Staff

Institute of Education, Reading University – John Oversby

Web Sites

Each theme has its own web site. There is also an Action Research web site. All are accessible from www.ukhipstgate.wikispaces.com

Materials available

Each web site has a selection of pages:

1. A teachers' page with personal subject knowledge: subject matter knowledge; misconceptions; research on teaching the topic
2. A Scheme of Work page: subject matter; philosophy; history; misconceptions
3. A lesson overview page to give details for pupils
4. Contexts pages divided into historical time sections: subject matter development; cultural changes; political changes

Lesson progress

The first topic, thermometry, is being trialled with Year 7 classes, at present at Yateley and Calthorpe Park. Progress is influenced by the length of lessons. 50 minute lessons make it difficult to complete more than one activity per lesson.

A pre-test is available: what is temperature? And why do scientists measure?

A pre-test on pupils' views about the nature of science is also given.

The 3 bowls experiment was quite well received, although there is a great variation in pupil recording depending on their literacy standards.

We have discovered a lack of familiarity with liquid-in-glass thermometers, and little idea of how they can be used, or how they are made. This has meant that some discussion of this has to be included. Many pupils come with a set idea that water always boils at 100 deg C, mainly from primary school. It has been difficult to let them into the minds of the early scientists.

The gas thermometer has been beset by equipment problems. The lack of mechanical pressure gauges in schools, and the short manometers available has meant that they can not be calibrated at both the ice point and the steam point. This has meant drastic modification. We are using newspaper formats for those parts that can not be hands on.

John Oversby