Creating Science – Sherbet and Measuring

What chemical makes the FIZZ of sherbet?

#CreatingScienceSherbet

Suggested outcomes

(This is by no means an exhaustive list of possible outcomes, neither is it intended that ONLY these outcomes can or should be met. Science is a deeply interrelated activity; all outcomes at all leaves, when appropriate, should be integrated.)

Science understanding

- Chemical sciences Year 2: Different materials can be combined, including by mixing, for a particular purpose.
- Chemical sciences Year 6: Changes to materials can be reversible, such as melting, freezing, evaporating; or irreversible, such as burning and rusting.
- Chemical sciences Year 9: Chemical reactions involve rearranging atoms to form new substances; during a chemical reaction mass is not created or destroyed (also, chemical reactions, including combustion and the reactions of acids, are important in both non-living and living systems and involve energy transfer).

Science inquiry skills

- Planning and conducting experiments (exact measures) 4-5: Suggest ways to plan and conduct investigations to find answers to questions.
- Planning and conducting experiments (exact measures) 4-5: Safely use appropriate materials, tools or equipment to make and record observations, using formal measurements and digital technologies as appropriate.

Science as a human endeavour

- Nature and development of science F: Science involves exploring and observing the world using the senses
- Nature and development of science 5-6: Science involves testing predictions by gathering data and using evidence to develop explanations of events and phenomena. And important contributions to the advancement of science have been made by people from a range of cultures.

Cross curricular outcomes

- Health and Physical Education: Personal, Social and Community Health. Being healthy, safe and active - Identify and practise strategies to promote health, safety and wellbeing (ACPPS036) – through making and eating food safely.

Disposal

All chemicals in this activity are safe to put down a sink.

Be sure to clean and reuse plastic spoons and cups.

Science vocabulary words

Tier 1 (Everyday words) – chemical, mix, test

Tier 3 (Specialised vocabulary)

- Chemical - the scientific term for 'substance' – all materials are, technically, chemicals, even stone, water and air.
- Acid – a chemical that reacts with a base.
- Base – a chemical that reacts with an acid.
- Alkaline – generally, a base that can also dissolve in water.
- Carbon dioxide – a very important chemical. Plants use it to build their bodies. The planet uses it to keep warm enough for us to live on. Humans use it to make fizzy drinks fizzy and to help them know when it's time to take a breath. But too much can be a bad thing – it can suffocate people, and too much might contribute to changing the planet's climate in ways humans will regret!

Warning

1. Only eat sherbet in small doses – the tip of a paddle pop stick, for instance. Larger doses can not only be very uncomfortable to eat, but can result in you accidently breathing in sugared sherbet. This is not only painful, it is a suffocation hazard. Be properly prepared and warned! Another reason for small doses – any small breath / hiccup / sneeze will result in a puffy cloud of sherbet that can get into and irritate eyes. It is also *very* messy.
2. Sugar. Loads of it. Some young people simply cannot handle sugar without becoming very silly or, literally, falling into a coma. Make sure you know if this is your group and act accordingly. You may also want to do this activity at the end of the day, not just so you don't have to deal with any hyperactivity, but because then they will have had the chance to still eat their normal, healthy lunches.
3. Depending on the flavouring you are using, allergies may also be a problem. It is a good idea to let families know beforehand the exact ingredients you will be using. Food manufacturers take it upon themselves to be extra careful, but it's always good to let families know.

Also

4. ***Despite repeated emphasis*** one student will eventually try to use ALL the citric acid or bicarb, leaving none for anyone else. Prepare appropriately – do not leave it all out at once!

Preparation

- icing sugar
- citric acid
- bicarbonate soda
- jelly crystals for taste
- spoons and something to level them, such as paddle pop sticks
- zip lock bags

Suggestions for other year levels

As always, more material is presented here than can be used by the average class during the average lesson time. However, since the student's questions can and should guide student learning, more material is presented for your convenience.

Younger:

Children at this age can have difficulty with focus. Avoid tangents if you're attempting to make a key point.

Middle:

This activity is well suited to this age group.

Teen:

Engage further in the development of acid/base theory, challenge students to develop their own response to the theory.

Invite students to understand and apply the chemical equations, learning to appreciate the concept in chemical science that: ***Matter is neither created nor destroyed, only changed***.

Learning Intent (student friendly)

'We are learning to' (WALT) – mix chemicals safely and effectively, and test the results.

Success criteria

'What I'm looking for' (WILF) – tasty, tasty sherbet, and an explanation of what is mixed, and what is made.

Student learning goals

Help students make a self-monitored learning goal for this lesson, such as 'measure chemicals properly' or 'make tasty sherbet'.

Evidence of learning

How will you know when the learning goal is achieved? What EVIDENCE do you have that your students have met or exceeded the learning expectations?

- A clear description of the chemical reactants and products (i.e., citric acid + bicarb = water + carbon dioxide gas, which is fizzy!)
- The sherbet tastes nice. Too much of any one ingredient might make the result *disgusting*.

Engage

Explain – chemicals are always mixing. But do you want to know what would happen if we took all the chemicals in the world and mixed them together? Want to know what we would get? [Mud – or something like sea water.]

You see, typically chemicals are very stable and boring. If we want to get a *big reaction*, we have to take chemicals that are very *different* in some way. One of those ways is acid/base reactions [see activity – red cabbage indicators].

⇨ Demonstrate an acid/base reaction using an overflowing cup (i.e. put a tablespoon of bicarb into a cup full of vinegar – over a sink of course!)

Explain - this is because when chemicals mix together, especially those with opposite properties, dramatic changes can occur. Why do you think this reaction happened?

⇨ Take some theories and explanations. Elaborate on the development of the acid/base theory [see end of document] as much as your students are benefited by it.

Ask: Do you think this is what is going on at a molecular level, far within where atoms can't be seen? What happens when we mix vinegar with bicarbonate soda?

⇨ Explain. According to theory this reaction takes place in two steps.

First, there is a reaction in which acetic acid in vinegar reacts with sodium bicarbonate to form sodium acetate and carbonic acid:

$$NaHCO_3 + HC_2H_3O_2 \rightarrow NaC_2H_3O_2 + H_2CO_3$$

Yet the Carbonic acid is unstable and falls quickly apart to produce carbon dioxide gas and water:

$$H_2CO_3 \rightarrow H_2O + CO_2$$

⇨ Therefore, in this reaction: acid + carbonate (base) = salt + water + carbon dioxide.

Ask: Can you think of a way to test this theory? (Not with classroom materials, but it is important to consider theories as ideas to be tested, not concepts to be simply memorised.)

Ask: Do we always get water and a salt when we add a base with an acid? To help us answer this, we will focus on a carbonate base, which will produce CO_2, which our bodies can detect.

Note: Indeed, this reaction *makes water* – many biological reactions do. But we still need more than our bodies can make so we have to drink water every day – especially after eating heaps of sherbet!

Explain: Carbon dioxide is very useful!

- This gas is the fizz in fizzy drinks. Huge amounts of it can be crammed among water molecules (which is why the coke and mentos activity works). This gas can even be found naturally in mineral water. Note – while it is fizzy, its taste isn't too great. Confectionary companies add *heaps* of sugar to cover the flavour.
- Carbon dioxide is a super important gas for keeping our planet warm enough to live on. It helps trap heat in, like a glasshouse does for plants.
  - However, scientists are legitimately concerned about the amount of carbon dioxide gas being released into the air in the last hundred or so years, due to the increase in industry such as cars and factories. Maybe the planet will get too warm on average, causing the climate to change all over the world…
- Carbon dioxide is the gas that our body can detect to tell us that we are suffocating. This is fascinating! It means we can't actually tell if we have too little oxygen in our lungs, only too much carbon dioxide (without oxygen we can suffocate without even knowing…).

⇨ Make sure all students write down any questions they may have generated during this phase regarding the topic for today.

Explain: we're going to try a simple, tasty activity to help us find evidence for the idea that acid + base (in this case, a carbonate base) can result in water and salt. The salt will break up to form fizzy CO_2!

Explore

Perform the activity "making sherbet" – See the book Creating Science

Remember safety.

Focus on exact measurements, and explain how:

- Striving for exact measurements is a virtue in science, allowing us to create more precise and reliable knowledge.
- It will greatly affect the edibility and tastiness of your experiment. Experiment with flavouring AFTER you've exactly measured your ingredients. Remember:
  - Too sour? Add bicarb.
  - Too salty? Add acid.
  - Too fizzy? Add sugar.
  - Not fizzy enough? Add bicarb and citric acid in equal amounts.

- Be careful not to underdo the measurements either! We're aiming for **exact**, not *minimal*. Having the citric acid equal to the bicarb will help.
- But don't overdo the need for accuracy; it is a virtue, not a tyranny. This activity allows for some flexibility and mistakes.

⇨ Ask students for suggestions on helping develop accurate measurements:
  - Use same spoons.
  - Use careful hands.
  - Use paddle pop sticks to make a 'flat' spoon.

Explain

⇨ The fizziness is one way of detecting the presence of carbon dioxide gas.

Therefore:

⇨ We have evidence that an acid + carbonate base does equal carbon dioxide!

Ask:

⇨ I wonder what else it creates…. Can you find out?

Tricky content for high school groups

For citric acid and sodium bicarbonate, the chemical reaction is as follows:

Citric Acid + Sodium Bicarbonate --› Carbon Dioxide + Water + Sodium Citrate [known as E331]

$$C_6H_8O_7 + 3NaHCO_3 \dashrightarrow 3CO_2 + 3H_2O + C_6H_5O_7Na_3$$

The theory is: acid + base = water and a salt.

In our case: acid + base (carbonate) = water and carbonic acid (break down to CO_2, and a citrate).

Note: **Not** all acids and bases create carbon dioxide and water, but **most acids** and **carbonate** bases do.

Elaborate

The breakdown of citric acid into carbon dioxide is happening right now inside your body (whether you've just had some sherbet or not). It is part of a very important biological process called the tricarboxylic acid cycle (TCA cycle) or the Krebs cycle, which is vital for helping turn the fuel in our bodies into energy.

By exchanging the sugar for corn-starch, and adding *a lot* more citric acid and bicarb (two heaped spoons each, for instance) – you have the makings of a relaxing bath bomb! Just remember to add essential oils instead of jelly crystals. You'll have to experiment to get this working right for you. Food colouring is often water based - can you figure out how to colour your bath bombs without setting off the acid-base reaction? [High school – remember, this reaction also creates water, so once the reaction gets starting it can really take off!]

Activity – Exploding cans (see Appendix):

This reaction can be a lot of fun! Now, if the chemical equation is correct, we should be producing a lot of carbon dioxide. If we are producing carbon dioxide air, we should be able to use that air to produce pressure.

- ⇨ Put some bicarb in an air tight can with a lid that can pop easily off, such as a milo tin. Add a cup full of vinegar *without spilling the vinegar*. Literally, place a cup with vinegar in the can, making sure none of the vinegar mixes with the bicarb yet. Press the lid carefully back on.
- ⇨ Take the temperature of the can using your hand on the base.
- ⇨ Shake the can to mix the two chemicals. With luck, the lid will explode off.
- ⇨ Test the temperature again with your hand on the base of the can, it will probably feel noticeably colder. Why? [Because all chemical reactions involve the absorption, or releasing, of heat. This one – acid and base – requires extra heat so it absorbs it from its environment.]
- ⇨ Ask: But are we *sure* acids and bases make carbon dioxide? Maybe they're making some other gas? Stick your tongue into the can, *but don't breathe in!* You might feel the fizz of carbon dioxide – and it will probably smell like vinegar as well.

Evaluate

- ⇨ Review with students what they feel they learnt from this lesson. Did they have any questions at the start that they feel were answered?

Success criteria

- ⇨ Review the Learning Intentions of this lesson with students. Were they met?
- ⇨ Did they manage to create a new material (carbon dioxide) and test for its presence (by tasting the fizziness) by carefully mixing other chemicals (citric acid and bicarbonate soda).

At the end of each class, review the learning objective and see how we did. Ask:

- Did you achieve your learning goal?
- What did you learn?
- What worked to help you achieve it?
- What might you do better next time?
- (If needed) where can you go for extra help or information?

Assessment

Prior learning:

Take time to focus on planned content material during the engage phase, for example,

- What is a chemical? [The scientific term for 'substance' – all materials are, technically, chemicals, even stone, water and air.]
- What happens when chemicals mix? [Often, nothing. But they can form new substances. When they do, they produce heat or absorb it.]
- How important is it to mix chemicals carefully? Accurately? [It depends]

Formative:

- What does it take to make an interesting chemical reaction? [*Different* chemicals, not heaps of chemicals randomly mixed.]
- Who invented the current theory of acid-base reactions? [It depends on which theory you're going to use!! Brønsted–Lowry is still popular high school choices, though Lewis trumps it in some university-level applications.]

Summative:

- Have students explain the acid – base reaction, and hypothesise on similar reactions:
    - Try lemon juice and bicarb – what will happen if lemon juice is an acid?
    - Try caustic soda (VERY DANGEROUS) and vinegar – predict results, but DO NOT EAT THEM!!!
- Older students might enjoy the challenge of describing the development of the theory of acids and bases.

So what?

- Science values exact measurements, which can be used to make food tasty!
- The theory of why acids and bases react the way they do has developed over hundreds of years, and is still in development! (See appendix – the acid base theory.)

Creating science

Science understanding

As we mixed chemicals we found that:

- Chemical sciences Year 2 and 6: Changes to materials can be reversible, such as melting, freezing, evaporating; or irreversible, such as burning and rusting.
- Chemical sciences Year 9: Chemical reactions involve rearranging atoms to form new substances; during a chemical reaction mass is not created or destroyed.

Science inquiry skills

As we used exact measurements and careful observations, we learnt:

- Planning and conducting experiments (exact measures) 4-5: Safely use appropriate materials, tools, or equipment to make and record observations, using formal measurements.

Science as a human endeavour

When we took time to create knowledge of acids and bases (particularly acids and carbonate bases making water and carbon dioxide) we learnt:

- Nature and development of science 5-6: Important contributions to the advancement of science have been made by people from a range of cultures.

Tips from the Masters

1. Use the CORRECT amount of chemicals, as suggested.
2. Don't eat too much sherbet or it makes you feel sick.
3. Do NOT breathe in sherbet. It HURTS!



Remember: not much citric acid, an equal amount of bicarb, and a whole lot of icing sugar!


And small tastes only!

The flavours of sherbet are as diverse as the scientists who make it!

Appendix – the acid base theory

How do we know that acid + base = water + salt?

(Much thanks to Wikipedia for taking the hard work out of this.)

Lavoisier's oxygen theory of acids

The first scientific concept of acids and bases was provided by Lavoisier circa 1776, where he defined acids in terms of their containing *oxygen*, which in fact he named from Greek words meaning "acid-former" (from the Greek οξυς (*oxys*) meaning "acid" or "sharp" and γεινομαι (*geinomai*) meaning "engender"). The Lavoisier definition was held as absolute truth for over 30 years, until the 1810 article and subsequent lectures by Sir Humphry Davy in which he proved the lack of oxygen in H_2S, H_2Te, and the hydrohalic acids. However, Davy failed to develop a new theory, concluding that "acidity does not depend upon any particular elementary substance, but upon peculiar arrangement of various substances".[2]

Liebig's hydrogen theory of acids

Circa 1838 Justus von Liebig proposed[3] that an acid is a hydrogen-containing substance in which the hydrogen could be replaced by a metal.[4] This redefinition was based on his extensive work on the chemical composition of organic acids, finishing the doctrinal shift from oxygen-based acids to hydrogen-based acids started by Davy. Liebig's definition, while completely empirical, remained in use for almost 50 years until the adoption of the Arrhenius definition.[5]

Arrhenius theory

Svante Arrhenius

The first modern definition of acids and bases was devised by Svante Arrhenius. A hydrogen theory of acids, it followed from his 1884 work with Friedrich Wilhelm Ostwald in establishing the presence of ions in aqueous solution and led to Arrhenius receiving the Nobel Prize in Chemistry in 1903.

As defined by Arrhenius:

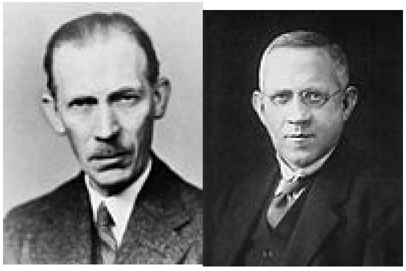
- *an Arrhenius acid* is a substance that dissociates in water to form hydrogen ions (H^+);[6] that is, an acid increases the concentration of H^+ ions in an aqueous solution.

- *an Arrhenius base* is a substance that dissociates in water to form hydroxide (OH^-) ions; that is, a base increases the concentration of OH^- ions in an aqueous solution.

This theory is no longer in use.

Brønsted–Lowry definition

Main article: Brønsted–Lowry acid–base theory



Johannes Nicolaus Brønsted and Thomas Martin Lowry

The Brønsted–Lowry definition, formulated in 1923, independently by Johannes Nicolaus Brønsted in **Denmark** and Martin Lowry in **England**, is based upon the idea of protonation of bases through the de-protonation of acids – that is, the ability of acids to "donate" hydrogen ions (H^+)—otherwise known as protons—to bases, which "accept" them.[11][note 1]

An acid–base reaction is, thus, the removal of a hydrogen ion from the acid and its addition to the base.[12] However, an acid and a base react not to produce a salt and a solvent, but to form a new acid and a new base. The concept of neutralization is thus absent.[2] Brønsted–Lowry acid–base behavior is formally independent of any solvent, making it more all-encompassing than the Arrhenius model.

For example, a Brønsted-Lowry model for the dissociation of hydrochloric acid (HCl) in aqueous solution would be the following:

$$HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$$

The removal of H^+ from the HCl produces the chloride ion, Cl^-, the conjugate base of the acid. The addition of H^+ to the H_2O (acting as a base) forms the hydronium ion, H_3O^+, the conjugate acid of the base.

Water is amphoteric—that is, it can act as both an acid and a base. The Brønsted-Lowry model explains this, showing the dissociation of water into low concentrations of hydronium and hydroxide ions:

$$H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$$

The Brønsted–Lowry model calls hydrogen-containing substances (like HCl) acids. Thus, some substances, which many chemists considered to be acids, such as SO_3 or BCl_3, are excluded from this classification due to lack of hydrogen. Gilbert N. Lewis wrote in 1938, "To restrict the group of acids to those substances that contain hydrogen interferes as seriously with the systematic understanding of chemistry as would the restriction of the term oxidizing agent to substances containing oxygen."[2] Furthermore, KOH and KNH_2 are not considered Brønsted bases, but rather salts containing the bases OH^- and NH_2^-.

Lewis definition

Further information: Lewis acids and bases

The hydrogen requirement of Arrhenius and Brønsted–Lowry was removed by the Lewis definition of acid–base reactions, devised by Gilbert N. Lewis in 1923,[13] in the same year as Brønsted–Lowry, but it was not elaborated by him until 1938.[2] Instead of defining acid–base reactions in terms of protons or other bonded substances, the Lewis definition defines a base (referred to as a *Lewis base*) to be a compound that can donate an *electron pair*, and an acid (a *Lewis acid*) to be a compound that can receive this electron pair.[14]

For example boron trifluoride, BF_3 is a typical Lewis acid. It can accept a pair of electrons as it has a vacancy in its octet. The fluoride ion has a full octet and can donate a pair of electrons. Thus

$$BF_3 + F^- \rightarrow BF_4^-$$

is a typical Lewis acid, Lewis base reaction. All compounds of group 13 elements with a formula AX_3 can behave as Lewis acids. Similarly, compounds of group 15 elements with a formula DY_3, such as amines, NR_3, and phosphines, PR_3, can behave as Lewis bases. Adducts between them have the formula $X_3A{\leftarrow}DY_3$ with a dative covalent bond, shown symbolically as ←, between the atoms A (acceptor) and D (donor). Compounds of group 16 with a formula DX_2 may also act as Lewis bases; in this way, a compound like an ether, R_2O, or a thioether, R_2S, can act as a Lewis base. The Lewis definition is not limited to these examples. For instance, carbon monoxide acts as a Lewis base when it forms an adduct with boron trifluoride, of formula $F_3B{\leftarrow}CO$

Adducts involving metal ions are referred to as co-ordination compounds; each ligand donates a pair of electrons to the metal ion.[14] The reaction

$$[Ag(H_2O)_4]^+ + 2NH_3 \rightarrow [Ag(NH_3)_2]^+ + 4H_2O$$

can be seen as an acid-base reaction in which a stronger base (ammonia) replaces a weaker one (water)

The Lewis and Brønsted–Lowry definitions are consistent with each other since the reaction

$$H^+ + OH^- \rightleftharpoons H_2O$$

is an acid-base reaction in both theories.

And yet the quest is still not over. None of these theories can account for every acid – base reaction we know of, and there are probably more we don't know about! Some other useful theories include:

Solvent system definition

One of the limitations of the Arrhenius definition is its reliance on water solutions. Edward Curtis Franklin studied the acid–base reactions in liquid ammonia in 1905 and pointed out the similarities to the water-based Arrhenius theory. Albert F. O. Germann, working with liquid phosgene, $COCl_2$, formulated the solvent-based theory in 1925, thereby generalizing the Arrhenius definition to cover aprotic solvents.[15]

Because the solvent system definition depends on the solute as well as on the solvent itself, a particular solute can be either an acid or a base depending on the choice of the solvent: $HClO_4$ is a strong acid in water, a weak acid in acetic acid, and a weak base in fluorosulfonic acid; this characteristic of the theory has been seen as both a strength and a weakness, because some substances (such as SO_3 and NH_3) have been seen to be acidic or basic on their own right. On the other hand, solvent system theory has been criticized as being too general to be useful. Also, it has been thought that there is something intrinsically acidic about hydrogen compounds, a property not shared by non-hydrogenic solvonium salts.[2]

Lux–Flood definition

This acid–base theory was a revival of oxygen theory of acids and bases, proposed by German chemist Hermann Lux[18][19] in 1939, further improved by Håkon Flood circa 1947[20] and is still used in modern geochemistry and electrochemistry of molten salts. This definition describes an acid as an oxide ion (O^{2-}) acceptor and a base as an oxide ion donor.

Usanovich definition

Mikhail Usanovich developed a general theory that does not restrict acidity to hydrogen-containing compounds, but his approach, published in 1938, was even more general than Lewis theory.[2] Usanovich's theory can be summarized as defining an acid as anything that accepts negative species or donates positive ones, and a base as the reverse. This defined the concept of redox (oxidation-reduction) as a special case of acid-base reactions

Appendix: Blowing the lid off milo tins

Activity (DANGEROUS):

Explain: When you mix an acid with a base, chemical change occurs! It often results in the two chemicals balancing each other out, becoming neutral. For example, mixing acetic acid (vinegar) with bicarbonate soda changes the chemicals, resulting in a chemically neutral solution. It also results in the creation of water and carbon dioxide gas, the latter of which can be used for all sorts of uses including making fizzy drinks fizzy or exploding the lids off cans! Finally, it's worth knowing that this reaction requires energy from the environment to function, making the surrounding area cooler. Remember - there are loads of other chemical reactions, this is just one!

Activity – the exploding can. You need an empty container with a press on lid. Metal containers with easy to press on lids, such as milo or other milk flavouring tins often work well. It needs to be a snug fit. If it's too easy to push the lid on, it'll come off too easily. If it's too hard it might not come off at all (or worse, explode out the side of the can along the seam). If there is a gap in the lid the air will all hiss out before making any impressive explosions.

- Place a handful of bicarb in the bottom of the container.
- Then place a cup of vinegar, still in the cup, in the milo tin.
- Press the lid on firmly.

Ask students what they think will happen if you shake the can and mix the chemicals. Have a student test the temperature of the can by touching the base with their whole hand. Then shake it.

WARNING:

Depending on your set up this activity can be extremely dangerous. You are, essentially, building a small explosion. The air pressure builds up inside the container until it is powerful enough to push the lid off. Depending on your set up, it may explode open with enough force to break bones, pop eyes, or embed the lid into the roof of your classroom. **Exercise extreme caution!** For example: point the container away from people, clear an adequate explosion zone, and make sure you don't use a lid so tight the entire container explodes. If the container fails to pop open, wait a while, then carefully lever the lid off with a screwdriver while standing well away – the container may still be under quite a bit of pressure and the lid may come out quite powerfully. If you hear a hissing sound, the air is likely escaping out from small holes and there will probably be no explosion (try another container).

Be careful with this one!!