SASTA OLIPHANT

SCIENCE AWARDS

SOUTH AUSTRALIAN SCIENCE TEACHERS ASSOCIATION

Prize Winner

Science Investigation

Year 7 - 8

Paris Nguyen
William Maddern

Immanuel College

ROWE SCIENTIFIC PTY. LTD. www.rowe.com.au

Government of South Australia
Department for Education

SASTA South Australian Science Teachers Association

Simple pop rocket, complex science

Aim

Test which acid makes a bottle rocket fly the furthest

Prediction

Vinegar will work the best because it is the acid used most often in pop rockets

Everyone has seen a variation of the acid and carb soda (sodium bicarbonate) pop rocket experiment at some time in their school life or on YouTube. Maybe it was the erupting volcano spewing its foamy mix or combining an Alka-Seltzer® tablet with water and shooting a film cannister high into the air. These a just two examples of the reaction when an acid is mixed with the base sodium bicarbonate to release CO2 (carbon dioxide) gas. It's a rapid and reliable chemical reaction that has wide applications and a long history

The science of how an acid combines with a carbonate to make carbon dioxide

When an acid is paired with a carbonate base, they undergo rapid acid-base neutralization reaction. Water is necessary to dissolve the dry powders and allow the acid and base to interact and produce carbon dioxide gas, water, and a salt.

The reaction of acetic acid (from vinegar) and sodium bicarbonate looks like:

$CH_3COOH + NaHCO_3 \rightarrow NaCH_3COO + (H_2CO_3) \rightarrow (H2O + CO2)$.

Acetic Acid + Sodium Bicarbonate → Sodium Acetate + (Carbonic Acid → Water + Carbon Dioxide)

Carbonic acid is only briefly present in the second stage of the reaction, very unstable, it rapidly converts to water and carbon dioxide.

Planning for the experiment

In our research we found 2 types of pop rockets using a compressed gas and liquid propellant system.

The first, a compressed air rocket, in which, air is mechanically pumped into a bottle containing some water. When sufficient gas pressure builds up, the bottle is then released from its locking system. The rocket moves in one direction as the mass of liquid is propelled in the opposite direction (due to the pressure of the escaping air). This follows Newtons Third Law of motion, 'For every action there must be an equal and opposite reaction'.

The second rocket propulsion system is an acid and soda rocket where the chemical reaction itself rapidly produces CO_2 gas inside the bottle before pushing out a cork and escaping with the liquid. In this system the liquid phase of the rocket is provided by the acid/water part of the system. We are going to test different acids with the same carbonate base to form the CO_2 gas; a reaction in which chemical energy transforms into potential energy as the CO_2 becomes compressed in the headspace of the rocket and then changes to kinetic energy as it releases from the rocket providing rocket thrust.

We know that liquid phase of the rocket propulsion system is important to achieving a significant launch distance. Without, it the compressed gas (air or CO_2) escapes quickly and the rocket is only launched a short distance.

From our research the optimal volume of liquid to compressed gas is approximately 1/3 of the bottle capacity. Above 1/3 volume and the mass of the liquid may negatively affect both the headspace (space where the compressed gas is forming) and be too heavy to lift rocket.

Why we have chosen these acids

We tested three organic acids that are safe to handle and readily available: acetic acid (in vinegar), citric acid and tartaric acid. Lemon juice was not used as it is a mixture of acetic, malic and ascorbic acids.

Vinegar (containing 5% acetic acid) is a liquid and citric and tartaric acids are powders that dissolve easily in water. We will make up 5% solutions of citric and tartaric acids to match the strength of acetic acid solution.

How we plan to compare the acids

Several reports state that the ideal bicarb-vinegar ratio (in terms of mass) is between 12:1 to 14:1. At 14:1 every 1 gram of sodium bicarbonate we add 14ml of vinegar. (contains 0.7g acetic acid) This is reported to produce the maximum amount of CO_2 and best propulsion distance of the rocket.

We decided to test the ratios of vinegar (acetic acid) with 5g sodium bicarbonate over a range of 6:1 up to 21:1 (and repeat this for the other acids). We wanted to find which ratio was best for the individual acid and compare acids to see if a particular acid has an advantage.

The sodium bicarbonate is present in a fixed amount in this experiment, and we expect that this will be the final limit on the production of CO_2 from the reaction.

This means we have 2 independent variables. First, we are comparing each acid individually at different test volumes (ratio) and measuring the rocket flight distance. Second, we are testing the 3 acids at the same test volume (ratio) and measure which acid produces the best flight distance at that ratio. We think this is a fair test.

What is our rocket

We decided to use a carbonated drink bottle without any modifications as our “rocket”. These bottles are designed to safely hold drinks with dissolved CO_2 and gas under pressure. Many demonstrations use a 2-litre bottle but to limit the amount of ingredients we needed, we chose a 300ml soft drink bottle and added a cork closure. We first considered measuring the height the rocket reaches after a vertical launch position but the heights of up to 20m we were reaching in our trials made this difficult and we decided that distance travelled, from a 45% launch angle would be adequate as our experiment is based on a comparison rather than the greatest distance travelled.

Independent Variables

The Independent variables are the amount and type of acid, and the dependent variable is the distance travelled by the rocket.

The constants are using the same amount of sodium bicarbonate, launch container (rocket), fuel loading method, launch pad and measurement.

Equipment

5x empty 300ml carbonated drink bottles (rocket launch)	
1x cork	
1x Electronic Kitchen scale	
18x 50ml Plastic sample tubes with lids	
1x Plastic long handled measuring spoon	
1x Adhesive Label and permanent marker	
1x Clear plastic jug with spout	
1x Small Plastic funnel	
1x Camping peg	
1x Launch assembly (timber stand pictured)	
1x Roll of soft toilet tissue	
1xPen and Paper	
1x Tape measure (30m)	
2x Protective safety glasses	
Ingredients	
Sodium Bicarbonate	
Vinegar	5% Acetic Acid (Bunnings)
Citric Acid powder	Gaganis Wholesaler
Tartaric Acid powder	Gaganis Wholesaler
Tap water	

Method

At Home	
1	Weigh 5g of sodium bicarbonate and place in a 50ml test tube and repeat x18
2	Prepare Citric Acid 5% solution (5% is 5g in 100ml water) For 300ml weigh 285g water into tared plastic jug Weigh 15g citric acid and add to water, stirring until dissolved (5min) and pour into empty 300ml bottle and label (repeat for second bottle)
3	Prepare Tartaric Acid 5% solution (5% is 5g in 100ml of water) For 300ml weigh 285g water into tared plastic jug Weigh 15g tartaric acid and add to water, stirring until dissolved (5min) and pour into empty 300ml bottle and label (repeat for second bottle)
At launch area	
1	Weigh the required volume of Vinegar (5% Acetic Acid) into tared plastic cup and use funnel to pour into launch bottle
2	Pour 5g portion of sodium bicarbonate into 2 squares of toilet tissue and wrap
3	Add the sodium bicarbonate pouch to bottle by squeezing it through the opening and force the cork into opening (tight fit)
4	Turn bottle upside down, shake 3 times and place in the launcher, cork down
5	Start timer when fuel pouch enters bottle/ stop timer when bottle launches, record
6	Observe where bottle lands, insert tent peg in grass
7	Measure distance from launcher to peg and record and then take out tent peg for reuse
8	Repeat process for each volume of acid fuel

The experiment was completed twice (on 2 different weekends).

Ratio of Acid: Sodium Bicarbonate and Acid Volume (ml) and Weight of Acid(g)

Ratio	Volume (ml)	Amount acid (g)
6:1	30	1.5
9:1	45	2.25
12:1	60	3
15:1	75	3.75
18:1	90	4.5
21:1	105	5.25

The experiment was completed twice (on 2 different weekends).

The results are presented as Experiments 1 and 2 showing a

- result table for each acid
- a graph showing all 3 acids with their test volume and the distance travelled

Results of Experiment 1

Table 1 Vinegar (Acetic Acid) / Baking Soda

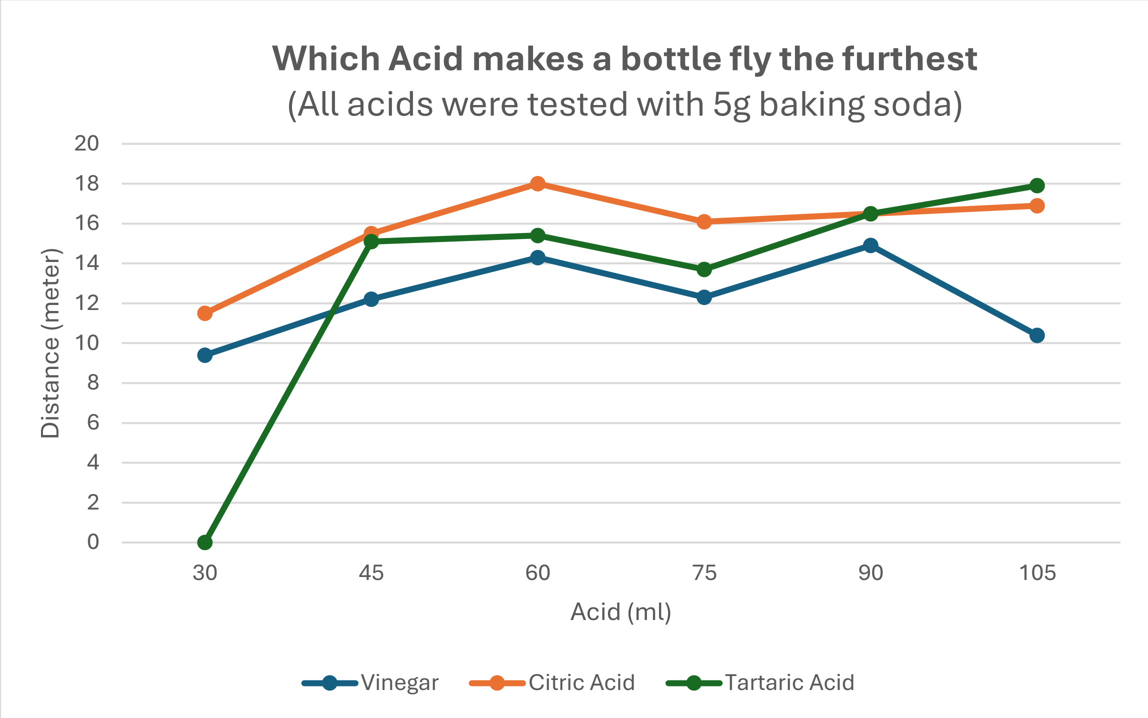
Ratio	Volume (ml)	Soda (g)	Time (min:sec)	Distance (m)
6:1	30	5	2:20	9.4
9:1	45	5	0:12	12.2
12:1	60	5	1:24	14.3
15:1	75	5	0:08	12.3
18:1	90	5	0:21	14.9
21:1	105	5	0:11	10.4
6:2	60	10	0:07	19.4

Table 2 Citric Acid 5% In water / Baking Soda

Ratio	Volume (ml)	Soda (g)	Time (min:sec)	Distance (m)
6:1	30	5	2:25	11.5
9:1	45	5	0:23	15.5
12:1	60	5	0:10	18
15:1	75	5	0:11	16.1
18:1	90	5	0:10	16.5
21:1	105	5	0:13	18.9

Table 3 Tartaric Acid 5% In water / Baking Soda

Ratio	Volume (ml)	Soda (g)	Time (min:sec)	Distance (m)
6:1	30	5	5:00	Did not launch
9:1	45	5	0:21	15.1
12:1	60	5	0:10	15.4
15:1	75	5	0:09	13.7
18:1	90	5	0:07	16.5
21:1	105	5	0:06	17.9



Experiment 2

Table 1 Vinegar (Acetic Acid) / Baking Soda

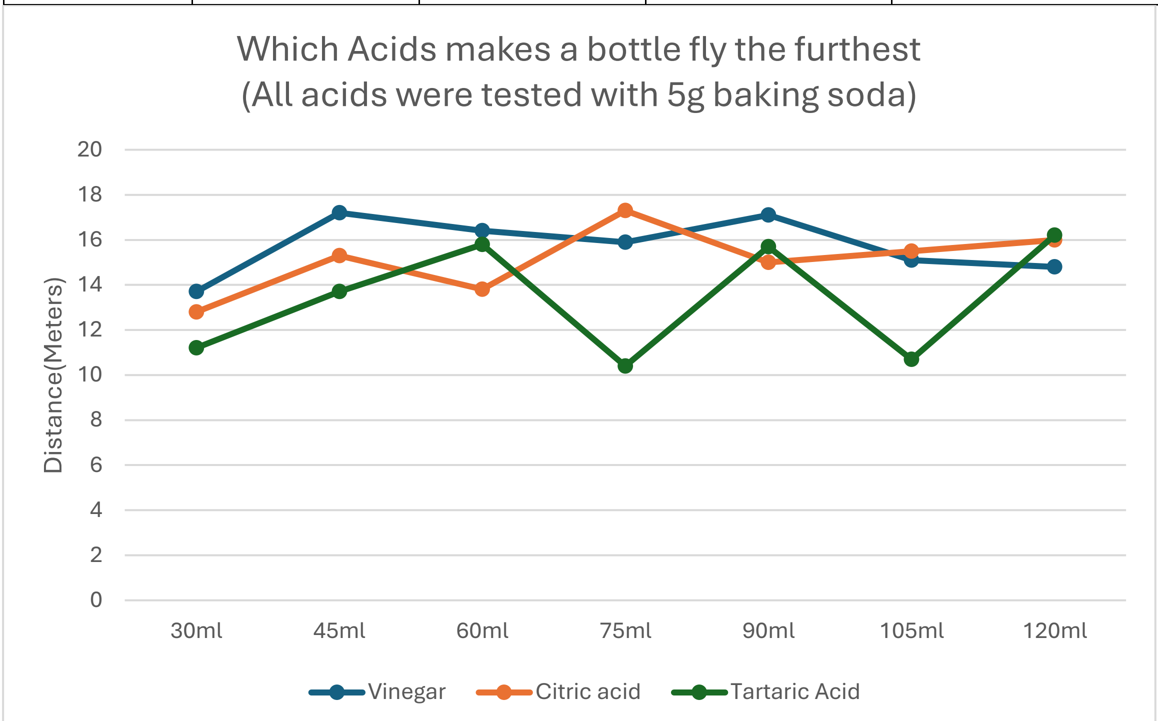
Ratio	Volume (ml)	Soda (g)	Time (min:sec)	Distance (m)
6:1	30	5	3:39	13.7
9:1	45	5	0:31	17.2
12:1	60	5	0:27	16.4
15:1	75	5	0:22	15.9
18:1	90	5	0:27	17.1
21:1	105	5	0:22	15.1
24:1	120	5	0:18	14.8

Table 2 Citric Acid 5% In water / Baking Soda

Ratio	Volume (ml)	Soda (g)	Time (min:sec)	Distance (m)
6:1	30	5	4:50	12.8
9:1	45	5	0:43	15.3
12:1	60	5	0:24	13.8
15:1	75	5	0:19	17.3
18:1	90	5	0:25	15
21:1	105	5	0:15	15.5
24:1	120	5	0:12	16

Table 3 Tartaric Acid 5% In water / Baking Soda

Ratio	Volume (ml)	Soda (g)	Time (min:sec)	Distance (m)
6:1	30	5	2:48	11.2
9:1	45	5	0:23	13.7
12:1	60	5	0:07	15.2
15:1	75	5	0:12	10.4 (Went very High)
18:1	90	5	0:12	15.7
21:1	105	5	0:08	10.7 (Went very high)
24:1	120	5	0:09	16.2



What does the experiment show

The results from Experiments 1 and 2 are different

Experiment 1

Citric Acid performed the best overall and recorded the maximum launch distance of 18.9m at volume of 105ml. The longest launch using tartaric acid was 17.9m with a ratio of 105ml and the acetic acid travelled 14.9m at its longest launch. The acetic acid (vinegar) was generally the weak performer.

Experiment 2

The results are more balanced. Acetic acid performed well reaching 17.5m at 90ml. Citric acid remained consistent and achieved 17.5m at 75ml. Tartaric acid was the most variable and at two volumes (75ml and 100ml) the bottle flew high in the air and the horizontal distance travelled was reduced.

Overall:

Vinegar shows a moderate consistency regarding the distance

Citric acid showed the high performances in both trials with small fluctuations and no major failure.

Tartaric acid showed a large swing between distance measurements.

Evaluation of the results

Our prediction was not confirmed. Citric acid outperformed the vinegar (acetic acid) and tartaric acid according to our results.

We can see that citric acid worked best within the acid volumes we tested with the sodium bicarbonate. At each acid volume we think the citric acid produced the most CO_2.

This may be due to the speed at which these chemicals create carbon dioxide when mixed.

The launch time results showed the larger acid volume generally reduced launch time by producing carbon dioxide more quickly. Tartaric acid produced the fastest launches, while citric acid generally produced the greatest flight distance. This means that the fastest reaction did not always create the most powerful launch, that total gas release may be more important than reaction speed alone.

While testing the ideal ratio of 12:1 to 14:1, the results show a steady increase in distance for all three acids from the 6:1 ratio to 12:1 ratio and around this time the graphs for all 3 acids to begin flatten out indicating that the maximum CO_2 production has occurred and all the sodium bicarbonate has been used up.

What else do we need to know about the Chemistry

When we look at the structures of the acid molecules, we find some differences

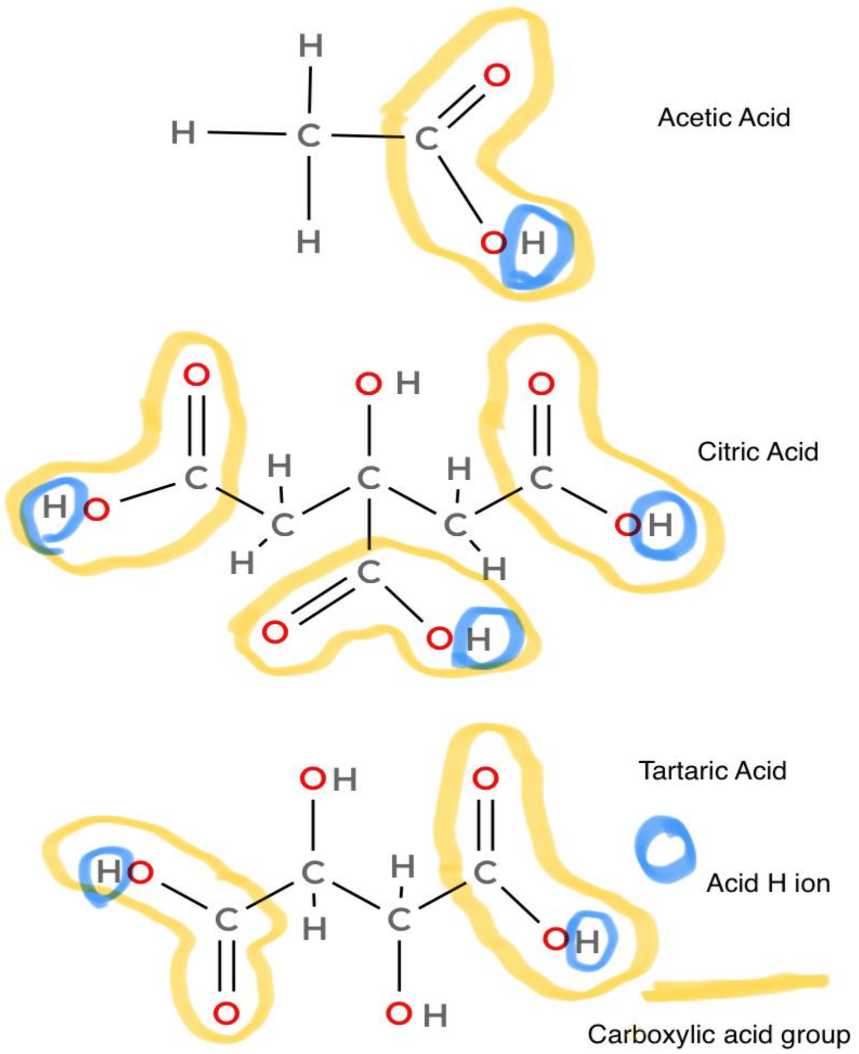


Figure 3. 2D Molecular Structure of Acetic Acid, Citric Acid and Tartaric Acid showing the reactive Acid H ions (Produced by William using Molview®)

Each of the three acids each have a different number of acid hydrogen ions (in carboxylic acid groups) that will combine with sodium bicarbonate:

Acetic Acid (1), Citric Acid (3) and Tartaric Acid (2).

This means in ideal conditions that each molecule of

Acetic Acid can react with sodium bicarbonate (1) and form CO_2 (1)

Citric Acid can react with sodium bicarbonate (3) and form CO_2 (3)

Tartaric Acid can react with sodium bicarbonate (2) and form CO_2 (2)

How does affect our interpretation? Each of the early data points show the volumes of Citric acid and Tartaric acid can react with more Sodium Bicarbonate producing CO_2 more quickly, reducing the launch times. This is generally observed in the results. We would expect that sodium bicarbonate would be "used up" quicker, the graph would flatten sooner and at lower volumes of acid. This was not observed.

Problems with our experiment

We thought that the horizontal distance was not necessarily an accurate measure of the rocket propulsion; sometimes the bottle rotated during flight increasing the drag and reducing the distance and, in some tests, the bottle went very high in the air but only travelled a short distance. The launch angle, variation of bottle position on the platform may not represent a fair test for rocket distance travelled.

Only two launches for each acid strength did not allow for consideration of an average measure.

Distance alone does not fully measure performance. Although we timed from insertion of the fuel pouch until launch (a measure of how quickly the CO_2 was generated) we were uncertain how to interpret this information apart from considering each acid and how many and how quickly donate their acid H ions. There could be significant human error in timing the reaction.

Air temperature (and test solution temperature), air pressure, humidity and winds were not controlled. The air temperature was around 18deg C for experiment 1 and likely around 14deg for experiment 2.

It was challenging to keep the test the same each time; from the way we loaded the fuel pouches and fitting the cork quickly with the same amount of pressure each time.

We don't know the quality of chemicals we used: the vinegar is stated as min 5% acetic acid on the Bunnings brand and the citric and tartaric acids do not state the purity. We weighed the ingredients on standard electronic kitchen scale (accuracy +/- 1g).

Future Investigations

We could solve some of our physical and aerodynamic problems if we worked out an efficient and accurate way to measure the vertical height of rocket launch.

It would be useful to find a bottle closure system that could guarantee an airtight system for capturing of CO_2 until launch and then to release the closure at the same gas pressure each time.

If we could measure the bottle pressure with a pressure gauge before launch it would show how much pressure each acid produces rather than only measuring the distance.

We may also want to try an experiment that varies the volume of liquid and headspace in the by testing a single acid (with a constant amount over the experiment) and vary its dilution volume, this could tell us at what point the mass of the liquid retards the rocket launch. We could compare different sizes of bottle: 600ml, 1.25L and 2L bottles.

We could change the independent variable to sodium bicarbonate and keep the acid constant and test the reverse.

By changing the acid concentrate: 2%, 3%, 4% this would alter the liquid volume and mass of rocket, it may show more information about the ideal acid, mass and thrust relationship.

To explore the chemical reactions of the acids further, we could look at the molecule ratios needed to get a complete reaction and convert this to the weight of acid needed using the molecular weight of the acids (using a science called stoichiometry).

Summary

Sometimes chemical reactions on paper look perfect and we expect that in a well-designed experiment the results would mirror this reaction. We believe from our results and our research that Acid – Carbonate Base reactions for rocket propulsion may not work exactly as the chemical equation suggests. Also, we need to look closely at how the physics and chemistry of rocket propulsion meet up, so we can make sure we are designing an experiment that only tests the efficiency of this fuel mix.

Whilst this is only pop rocket science, proving that a chemical reaction is predictable and efficient is important in many industries so that chemicals are not wasted and to limit the production of unwanted by products.

Logbook is a separate document.

Risk assessment form for scientific investigation is a separate document

Word count (not including tables, text boxes, and headings): 2150

Assistance: school science teacher (for reminding us of deadlines), parents for making the launch platform.

Reference list

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Software used

Molview®- chemical structures, Excel - graphs

Photos of the Experiment

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Measuring acid

Creating the soda sausage

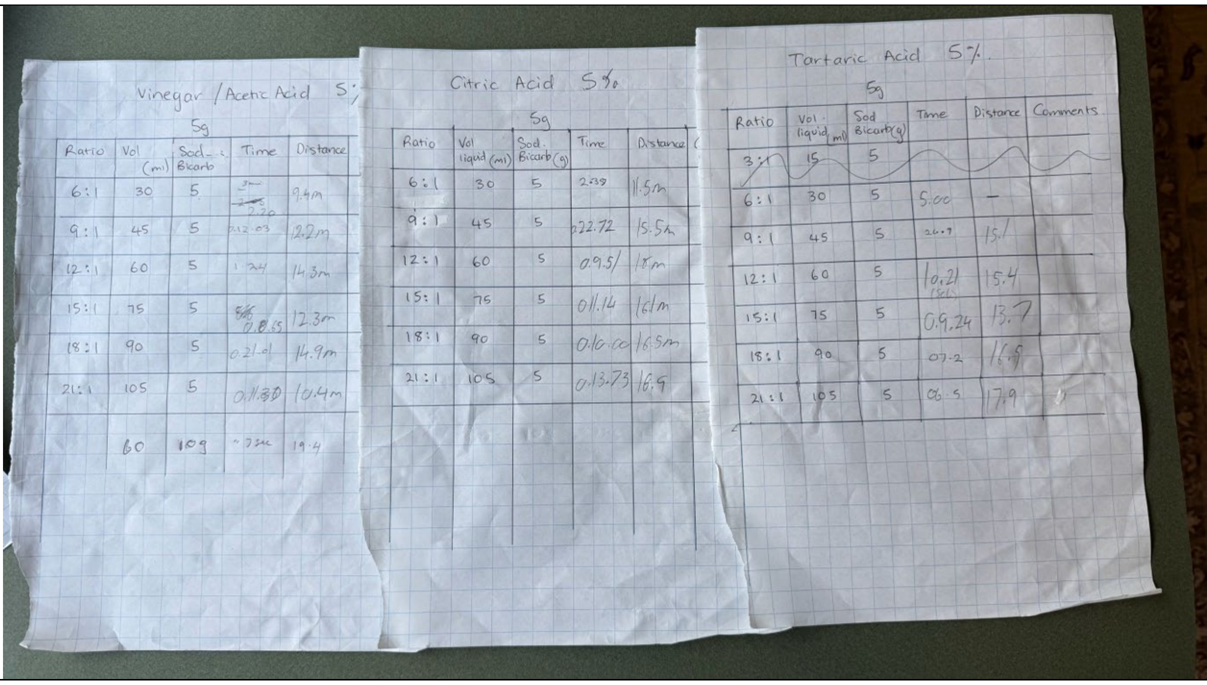
Placing the soda in the bottle

The bottle is in the launcher

Measuring the distance

Logbook Paris Nguyen and William Maddern

Date	Activity
19/3/26	Oliphant science meeting at school Paris, William decided to do a science inquiry on pop rockets and test what acids work best with soda to make rocket go the highest
	Individual research
From 4/5/26 2 weeks	William – looked at YouTube videos on Compressed air/water rocket (purpose to work out the gas/liquid ratio needed to get thrust, practice on drawing molecular structure of acids, discussion with mum about what H ions react from organic acid molecules, watched YouTube on molar calculations but decided too hard to calculate molar amount of acids to match up with carbonate and the weight of acid needed for this
28/4/26	William tried a couple of different bottles at home, sauce bottles with attached cap, did not work because the cap leaked the CO2 gas and bottle did not launch Plan use carbonated drink bottle with tight fitting cork
24/5/26	Paris, William went to park with empty soda bottle, vinegar and sodium bicarbonate and tried launching 600ml bottle and cork from vertical position and measure height (using vinegar and soda, then citric acid and soda), launched from vertical position using empty yoghurt tub as platform, height over 10m too difficult to measure against shade sail pole, discussed option of using laser measure. **<u>Plan</u>** to measure horizontal distance instead, decided that 3 test acids include Acetic acid vinegar, citric acid and tartaric acid at different ratio/ weight to constant weight sodium bicarbonate
27/5/26	William's dad built timber launch angle at 45deg and measure horizontal distance
28/5/26	William went to park tried timber launch platform with 300ml bottle and cork combination of vinegar 50ml, 75ml with sod bicarb 5g and 7.5g proof can measure horizontal distance of launch, and you can time the event between loading the bottle and launch. **Thinking**: launch platform works well, consistent flight pattern
31/5/26	Paris, William at park to run the experiment 1 (see data) with timber launch platform William made up 5% citric acid and 5% tartaric acid solutions (600ml) at home and Paris and William weighed out 5g portions of sodium bicarbonate in sample tubes before the experiment. **Thinking**: it went ok, method was clear and consistently followed, tried a couple of extra tests at the end with leftover ingredients
31/5/26	See Raw Data experiment 1



Vinegar / Acetic Acid 5%

5g

Ratio	Vol (ml)	Sod- Bicarb	Time	Distance
6:1	30	5	3min ~~2.~~ 2.20	9.4m
9:1	45	5	0.12.03	12.2m
12:1	60	5	1.24	14.3m
15:1	75	5	~~8.6~~ 0.8.65	12.3m
18:1	90	5	0.21.01	14.9m
21:1	105	5	0.11.30	10.4m
	60	10g	~7sec	19.4

Citric Acid 5%

5g

Ratio	Vol liquid (ml)	Sod. Bicarb (g)	Time	Distance
6:1	30	5	2.38	11.5m
9:1	45	5	0.22.72	15.5m
12:1	60	5	0.9.51	18m
15:1	75	5	0.11.14	16.1m
18:1	90	5	0.10.00	16.5m
21:1	105	5	0.13.73	16.9

Tartaric Acid 5%

5g

Ratio	Vol liquid (ml)	Sod Bicarb (g)	Time	Distance	Comments
~~3:1~~	~~15~~	~~5~~			
6:1	30	5	5.00	–	
9:1	45	5	26.7	15.1	
12:1	60	5	10.21 (sec)	15.4	
15:1	75	5	0.9.24	13.7	
18:1	90	5	07.2	16.5	
21:1	105	5	06.5	17.9	

6/6/26

Shared data and started writing report (share write up and feedback with each other, discuss sections needed in report (Paris constructed graph showing results)

Thinking: divide work up, ask some questions we need to answer in the report

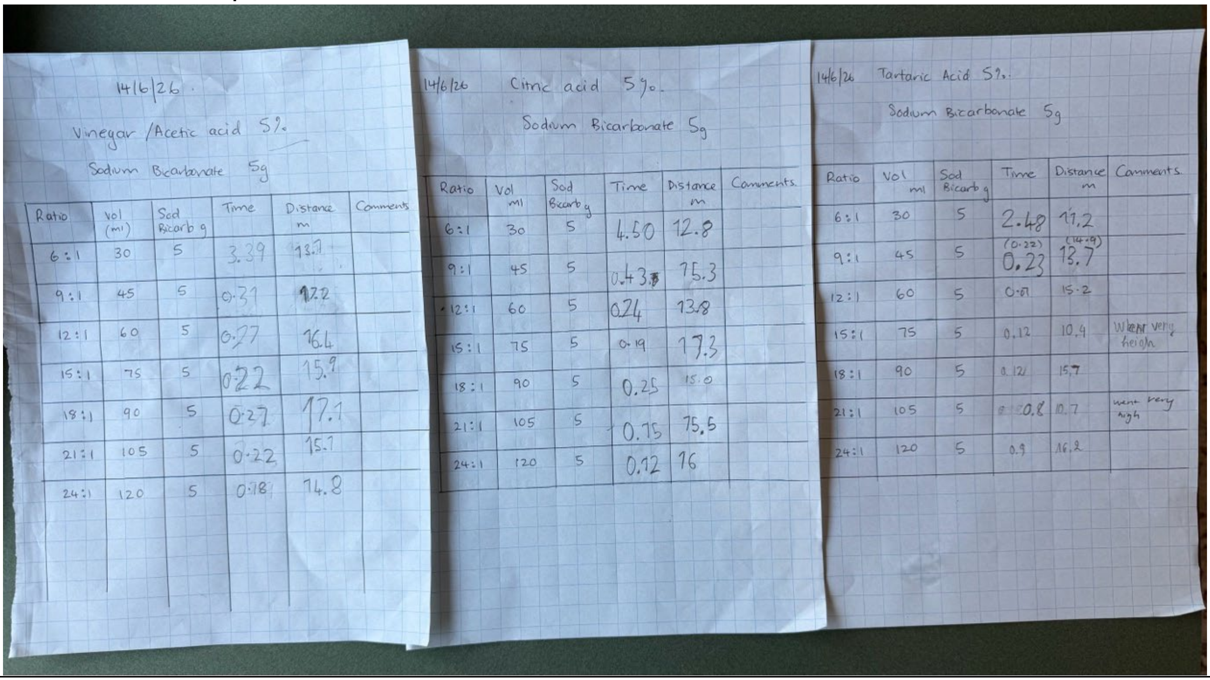
14/6/26

Repeat with experiment 2 at local park at 4pm, to speed up the experiment the fuel pouches of sodium bicarbonate were wrapped into "burritos" at home instead of the park

Thinking: results were different to experiment 1, a lot more variation in bottle flight, a couple of times it spun a lot in flight, and twice it went very high and landed unexpected short distance, more variation in times to launch as well, maybe air temp at 4pm 14deg C affected chemical reaction rate

14/6/26

See Raw Data experiment 2



14/6/26

Vinegar / Acetic acid 5%

Sodium Bicarbonate 5g

Ratio	Vol (ml)	Sod Bicarb g	Time	Distance m	Comments
6:1	30	5	3.39	13.7	
9:1	45	5	0.31	12.2	
12:1	60	5	0.27	16.4	
15:1	75	5	0.22	15.9	
18:1	90	5	0.27	17.1	
21:1	105	5	0.22	15.1	
24:1	120	5	0.18	14.8	

14/6/26 Citric acid 5%

Sodium Bicarbonate 5g

Ratio	Vol ml	Sod Bicarb g	Time	Distance m	Comments
6:1	30	5	4.50	12.8	
9:1	45	5	0.43.[illegible]	15.3	
12:1	60	5	0.24	13.8	
15:1	75	5	0.19	17.3	
18:1	90	5	0.25	15.0	
21:1	105	5	0.75	15.5	
24:1	120	5	0.12	16	

14/6/26 Tartaric Acid 5%

Sodium Bicarbonate 5g

Ratio	Vol ml	Sod Bicarb g	Time	Distance m	Comments
6:1	30	5	2.48	11.2	
9:1	45	5	(0.22) 0.23	(14.9) 13.7	
12:1	60	5	0.07	15.2	
15:1	75	5	0.12	10.4	Went very heigh
18:1	90	5	0.12	15.7	
21:1	105	5	0.8	10.7	went very high
24:1	120	5	0.9	16.2	

19/6/26

Meeting to continue writeup and select photos, go over results and write evaluation together, use project checklist organise and allocate remaining tasks

22/6/26	Meet with school science coordinator for feedback on write up Feedback We focused mainly on the logbook and the submission process.
19/6/26	Went to Marion library and collaborated to work further on the document
21/6/26	Went to Marion library and collaborated to work further on the document
23/6/26	We deleted the history because we needed to cut words.

OSA RISK ASSESSMENT FORM

for all entries in (✓) ☐ Models & Inventions and ☑ Scientific Inquiry

This must be included with your report, logbook or entry. One form per entry.

STUDENT(S) NAME: Paris Nguyen and William Maddern ID: ______________

SCHOOL: Immanuel College

Activity: Give a brief outline of what you are planning to do.

We are planning to use 3 types of acids with baking soda, Tartaric Acid, Citric Acid and Vinegar to make a bottle rocket fly.

Are there possible risks? Consider the following:

- Chemical risks: Are you using chemicals? If so, check with your teacher that any chemicals to be used are on the approved list for schools. Check the safety requirements for their use, such as eye protection and eyewash facilities, availability of running water, use of gloves, a well-ventilated area or fume cupboard.
- Thermal risks: Are you heating things? Could you be burnt?
- Biological risks: Are you working with micro-organisms such as mould and bacteria?
- Sharps risks: Are you cutting things, and is there a risk of injury from sharp objects?
- Electrical risks: Are you using mains (240 volt) electricity? How will you make sure that this is safe? Could you use a battery instead? **Only batteries can be used for Models & Inventions entries*
- Radiation risks: Does your entry use potentially harmful radiation such as UV or lasers?
- Other hazards.

Also, if you are using other people as subjects in an investigation you must get them to sign a note consenting to be part of your experiment.

Risks	How I will control / manage the risk
Bottle flying into face Acid splatting into face Acid Spillage	Standing back at a safe distance Glasses and protective clothing Cloth to clean up

(Attach another sheet if needed.)

Risk Assessment indicates that this activity can be safely carried out

RISK ASSESSMENT COMPLETED BY (student name(s)): William Maddern

Paris Nguyen

SIGNATURE(S): ______________________

☑ By ticking this box, I/we state that my/our project adheres to the listed criteria for this Category.

TEACHER'S NAME: Samuel Munday

SIGNATURE: ______________ DATE: 23/6.2026