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Scientific Inquiry

Year 9-10

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CARBON CAPTURE

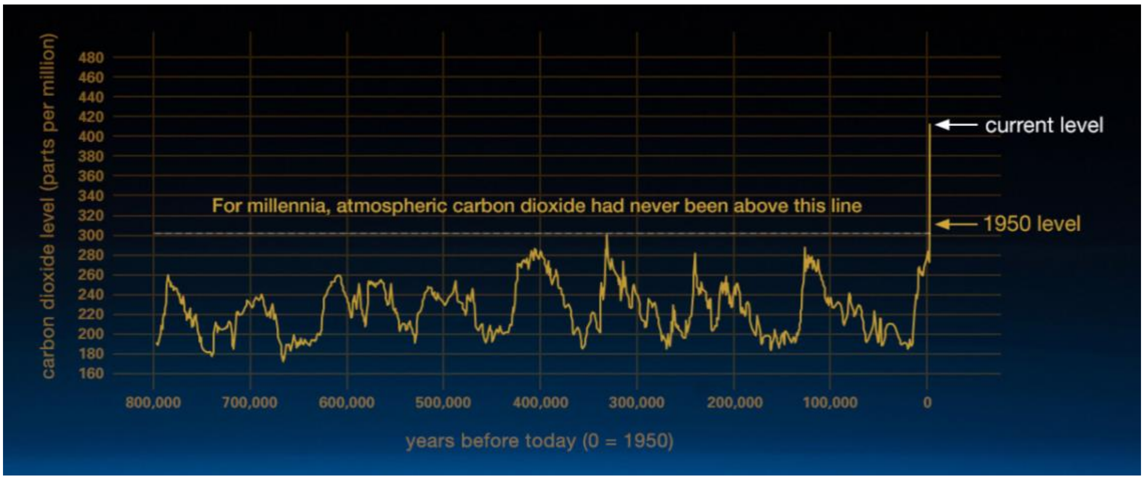
COULD THIS BE HOW WE SAVE THE PLANET?

Emily Estcourt Hughes

2192 words

Climate change is a critical world issue. The effects of climate change can already be seen in the environment and if we don't start to act now, temperatures will continue to rise, we will experience more severe droughts and heatwaves and more frequent wildfires(Nasa, n.d.). By 2100 the sea level will rise 1-8 feet, 70-100% of all coral reefs will be bleached or dead and it is expected that before 2050 we will have an ice free arctic in the summer(WWF, n.d.). Also, plants and animals will lose more habitat causing many more species to become extinct.

Global warming and climate change are mainly due to the human expansion of the greenhouse effect. The greenhouse effect is a natural effect, trapping the sun's warmth in the lower atmosphere to maintain temperature. This is done by certain gasses that block heat from escaping. These are water vapour, nitrous oxide, carbon dioxide(CO2) and methane. However, Human activities are changing the natural greenhouse. Over the last century burning fossil fuels like coal and oil have drastically increased the concentration of atmospheric CO2. This is causing global warming. The graph below shows CO2 levels over the past 800,000 years compared to today.



A graph showing atmospheric CO2 concentration in the past compared to currently (Nasa,n.d.)

However, there is already too much CO2 in the atmosphere. Scientists estimate that to hold the rise in global average temperature at 1.5°C above the preindustrial baseline, which is considered a safe level of warming, humans must stabilise the atmospheric concentration of CO2 at around 350 PPM(Roberts, 2019). The current level as of the 17th of July 2021 was 418.87 PPM(CO2.earth, 2021). So if we want to secure the climate for future generations, we can't just reduce carbon emissions, we need to remove CO2 from the atmosphere. This is done through carbon capture. Carbon capture is finding techniques and materials to pull CO2 out of the air to be safely disposed of.

This report will be looking at carbon capture using amines, specifically Triethanolamine. Amines are organic compounds which contain and are often based around one or more atoms of nitrogen(organic chemistry II). This report will be investigating how volume effects the rate of CO2 capture by amines in a closed environment. This will be done by measuring how long it takes for varying volumes of amines from 1ml-20ml to absorb all the CO2 in a container. The measuring instrument will be a CO2 probe.

Questioning and Predicting

Aim

The aim of this experiment is to determine how volume effects the rate of CO_2 capture by amines in a closed environment.

Hypothesis

The hypothesis is that the larger the volume of amines, the faster carbon dioxide will be absorbed.

Planning and Conducting

This method was chosen as it was the most valid way to perform the experiment to answer the question, while controlling variables, with the resources that were available.

Independent variable

The independent variable in this experiment was the volume of amines. This will be varied by having volumes of 1ml, 5ml, 10ml, 15ml and 20ml.

Dependant variable

The dependant variable in this experiment was the rate at which the different volumes of amines absorbed CO_2. This was measured by the time taken for the CO_2 concentration in a container to reach 0 PPM.

Controlled variables

Variable	**How it was controlled**	**Why it needed to be controlled**
Volume of the container	By using the same 300ml container for each sample group	If one container had more air than another there would be more CO_2 for the amines to absorb which would take longer.
Type of amine	By using Triethanolamine throughout the experiment	Different amines have different compositions and properties so some would have absorbed CO_2 better than others
Concentration of Triethanolamine	Fully concentrated Triethanolamine was used and it was made sure the containers were dry before the experiment.	When concentration is increased, the reaction proceeds more quickly as there is an increase in the number of molecules that have the minimum required energy.
Available surface area for the amines to cover	By using the same container, standing in the same position for every experiment.	In a trial experiment it was proven that the larger the surface area, the faster the reaction.
Variation in probe measurement	The probe was calibrated before each different variable was tested.	The probe would become uncalibrated and measure much

		higher CO_2 levels causing measurements to be incorrect.
The time taken to transfer the amines from the bottle to sealing the container.	2 minutes was taken to measure the correct amount of Triethanolamine and 1 minute was taken to pour the triethanolamine into the container. The container was sealed using the probe and stopper at the end of the minute.	The reaction was occurring between the air and the triethanolamine as it was being transferred from the bottle to the container. If this was not controlled some of the amines would have been performing the chemical reaction for longer than others.
Measurements of the container	By using the same container for each sample group.	Containers having different measurements would cause the amines to be covering different surface areas, which can effect reaction rate

Collection of sufficient data

Five different volumes of triethanolamine were chosen to be tested. These were 1ml, 5ml, 10ml, 15ml and 20ml. These volumes were chosen as the container that needed to be used with the CO_2 probe was only 300ml meaning that only a small volume of amines was needed to absorb the CO_2. The reaction with a volume of 20ml had proven to be quite fast in trial experiments so was the largest volume chosen to be tested, if any higher volumes were chosen, the points on a graph would not have enough variation. Five smaller measurements under 20ml were chosen so that there would be a good spread of results.

Apparatus

- 54ml of Triethanolamine
- Carbon Dioxide Gas Probe with the stopper and the container that come with the probe
- A laptop with SPARKvue software
- 50ml measuring cylinder
- 10ml measuring cylinder
- Sticky tape
- Paper towel

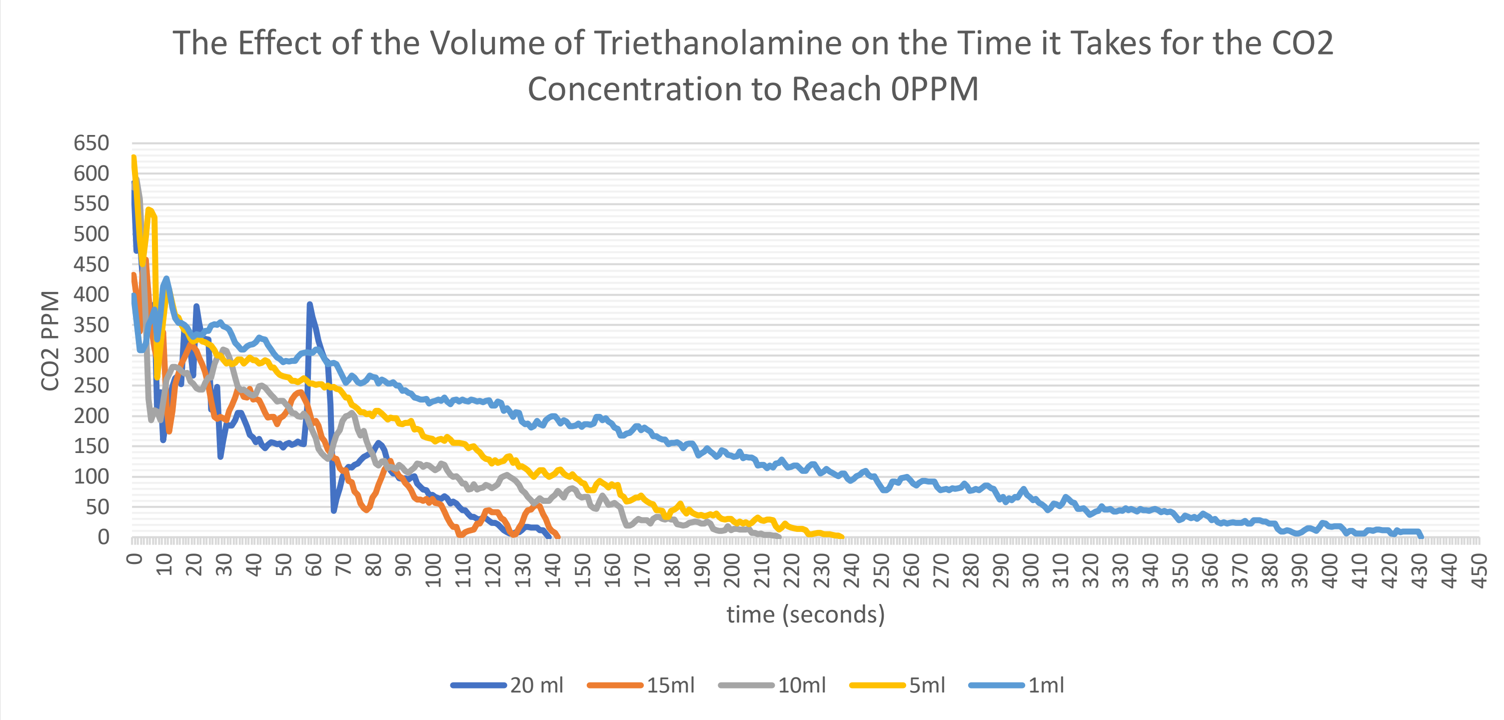
Method

1. A new file was set up on spark view on a laptop
2. The CO2 probe was connected to the laptop
3. The container was stuck to the surface it was sitting on using sticky tape
4. The CO2 probe was calibrated
5. The bottle cap was taken off the bottle of Triethanolamine and the stopwatch was started
6. 2 minutes were taken to measure the correct volume of Triethanolamine (1ml, 3ml, 5ml, 10ml, 15ml, 20ml) using the measuring cylinder (a 50ml measuring cylinder was used for volumes 20ml, 15ml and 10ml and a 10ml measuring cylinder was used for volumes 5ml,3ml and 1ml)
7. 1 minute was taken to pour the triethanolamine measured from the measuring cylinder into the container and the container was prepared for the probe to be attached
8. As soon as the minute ended the probe was secured in the container and was sealed using the stopper, the graph was started
9. The graph was stopped after the CO2 concentration reached a stable level of 0 without rising
10. The graph was downloaded onto a USB
11. The CO2 probe was removed from the container
12. The stopper was removed from the probe and was cleaned using paper towel
13. The stopper was cleaned using paper towel
14. The stopper was connected back onto the probe
15. The container was rinsed and dried
16. The measuring cylinder was rinsed and dried
17. Repeat steps 1-15 for all concentrations of amines (1ml, 3ml, 5ml, 10ml, 15ml, 20ml)

Safety

The only potential safety hazard involved in this experiment was the use of Triethanolamine. This is a Hazardous liquid. This risk was controlled by wearing a lab coat when transferring the Triethanolamine and contact with skin was avoided. Any spilt Triethanolamine was cleaned up immediately and hands were washed regularly throughout the experiment.

Processing and Analysing Data and Information



Total time taken for the CO_2 concentration to reach 0PPM using different volumes of Triethanolamine

Volume of Amines (ml)	**Time Taken for CO2 Concentration to Reach 0 PPM (seconds)**
1	431
5	237
10	216
15	142
20	139

The Effect of the Volume of Triethanolamine on the Time it Takes for the CO_2 Concentration to Reach 0PPM (Selected Data)

Time (s)	Volume of Triethanolamine				
	20 ml	15ml	10ml	5ml	1ml
0	584	433	577	627	399
10	160	338	223	357	414
20	267	315	254	323	331
30	159	196	310	293	348
40	164	227	234	292	319
50	148	200	225	266	289
60	364	188	175	254	304
70	99	109	192	238	266
80	138	65	138	200	265

90	96	97	115	187	241
100	70	63	114	162	224
110	45	4	89	155	227
120	24	41	81	121	217
130	12	23	78	117	191
139	0				
140		10	65	102	200
142		0			
150			65	90	182
160			54	87	188
170			28	69	176
180			29	43	156
190			23	37	138
200			12	30	135
210			6	28	119
216			0		
220				16	116
230				7	105
237				0	
240					93
250					84
260					94
270					77
280					76
290					62
300					67
310					51
320					37
330					44
340					43
350					28
360					33
370					24
380					23
390					6
400					18
410					6
420					12
430					9
431					0

In this experiment it has been found that there is a significant relationship between the volume of triethanolamine and the speed of CO2 absorption. The greater the volume of triethanolamine, the faster the CO2 was absorbed. This can be seen in the results as the faster the CO2 concentration reached 0PPM the faster the CO2 was absorbed by the triethanolamine. The container containing 20ml of Triethanolamine reached a CO2 concentration of 0PPM the fastest, then 15ml, 10ml, 5ml with 1ml taking the longest. There was no obvious mathematical relationship between the volume of amines and how long it takes for the CO2 concentration levels to reach 0 and the results were not proportional.

The AIP Conference Proceedings 1864, 020091 (2017) and Catalysis for Energy Storage and CO2 conversion (2019) studies have shown that CO2 absorption by amines is better in an alkaline pH balanced environment. When the reaction occurs the products are an amine and a carbamate. The carbamate is a carboxyl group which is acidic. As the reaction takes place and more molecules undergo the reaction, more carbamate is made and the amine solution becomes more acidic, this causes the reaction to slow down. In lower volumes, the carbamate is more concentrated and the solution is more acidic, which caused the reaction to progress slower. This reaction is shown below where the amine is R-NH_2(Huertas, 2015)

$$2\text{R-NH}_2 + \text{CO}_2 \longleftrightarrow \text{R-NH}_3{}^+ + \text{R-NH-COO}^-$$

Amine	Carbon dioxide	Amine	Carbamate – carboxyl group

The hypothesis was supported by the results. It was hypothesised that the higher the volume of amines, the faster the carbon dioxide was absorbed. This was shown in the results. However, this hypothesis may not always be true. In this experiment the smallest variation in the independent variable was 4ml, between 5ml and 1ml, this hypothesis may have not been true if the same experiment was done with a 1ml variation between volumes, for example 1ml, 2ml, 3ml. This hypothesis may also not be true if this experiment was done with higher volumes of amines, eventually the reaction gets quite fast so there may be a point where the reaction doesn't get any faster.

There was one main anomalous point however there was not one independent variable result that was an anomaly. This point was in the 20ml variable at 59 seconds. It is not likely that this was due to air entering as a vacuum was created inside of the container as there was no trend showing this, if air had entered it is likely it would have happened repeatedly. As such, the anomalous result was most likely an error caused by the CO2 probe used. The first 20 seconds of measurements are very haphazard and contain lots of anomalous results, large jumps, that do not fit onto the line of best fit. This is due to the fact that the probe had just been entered onto the container and took time to acclimate to the closed environment and measure the CO2 levels thoroughly. However, after 20 seconds the points, aside from the anomalous result mentioned earlier, all fit quite closely on the line of best fit and created a nice curve. The variation between the variables results is quite haphazard with some being close and others being spaced apart, for example 20ml and 15ml results were close where as 15ml and 10ml were further apart. This shows that more repeats may be needed work out the exact increments between the different variables reliably.

Evaluating

The method was valid for the purposes of finding how the volume of amines effect the rate and efficiency of CO_2 capture by amines in a closed environment. Sufficient data was collected however a wider range of amine volumes would have helped to further address and understand the aim. This would have allowed for exploration of how higher volumes of amines effect the speed and efficiency. Repeating the experiment would have allowed for more reliable results as an average time could have been calculated over the repeats. The measuring instrument, a CO_2 probe effectively measured the time that it took for the CO_2 concentration to reach 0PPM. The CO_2 probe took a measurement every second, compiling good results. A disadvantage of using the CO_2 probe and method used is that the first 20 seconds of results were haphazard and unreliable, this could have been resolved by injecting the Triethanolamine into the container while the CO_2 probe was already in there so that the probe was already acclimated to the closed environment. This method could have also been improved by using a larger container. This would contain more CO_2 so that absorption could be seen over a larger period of time, it also shows more potential to have success in an open-air environment and would allow for it to be seen if volume has an effect on total CO_2 that can be absorbed. Another improvement to the design would be to use a different chemical that show better CO_2 absorbing properties such as MOFs, lithium hydroxide or zeolites. However, these chemicals are much more expensive and harder to source so were not accessible through the school labs for this experiment. The method effectively tested the hypothesis and addressed the aim as most of the crucial variables that could be controlled were kept relatively consistent. However, there were some sources of error, these have been summarised in the table below.

Source of Error	**Significance of the error**	**Suggested Improvements**
Starting CO_2 concentration	The starting CO_2 concentration inside the container varied significantly with a scatter of 228 PPM. This seemed to level out quite quickly as after 20 seconds the scatter was 77 PPM which was the smallest scatter in results throughout the experiment. However this still would have had an effect on the results.	All of the variables could be tested at once so that time does not allow for a change in atmospheric CO_2 or the experiment could be started at a known CO_2 concentration.
Errors caused by the CO_2 probe	The CO_2 probe measurements jumped around a lot when it was sitting in open air showing that there may be some errors caused, by jumping measurements. This only had a small effect on results as a reliable trend line can be seen.	Find a way to access to a higher quality probe or use two probes at once and averaging the data or repeating the experiment to create an average.
Temperature	The significance of this error cannot be measured as the	Temperature could be monitored throughout the experiment or if changes in

	temperature was not monitored or measured.	temperature were significant have the container in a water bath set to a certain temperature. This is the case as there was only one probe so not all variables could be tested at one time.
Air in the Triethanolamine bottle	As the Triethanolamine was poured out of the bottle, more air was stored in the bottle, the lid was also left off of at different times. This could mean that the triethanolamine could have been undergoing a reaction inside of the bottle. This variable would have only had a small effect as the change to the air in the bottle would have been small.	Use triethanolamine that hadn't been previously exposed to air. This could be done by packaging the triethanolamine in small airtight packages that have a small amount so that it is only used once.

The findings of this investigation could be very useful to anyone working to combat climate change and global warming. This data would be useful for anyone trying to scale this experiment so that it can absorb CO_2 on a larger scale. With the data from this experiment, people can see how 1ml reacts compared to 20ml as well as the values between to help find the optimum volume where the amine is most effective without wasting resources.

Some questions for further investigation include:
How does the volume of amines effect the total CO_2 that can be absorbed?

How does temperature effect this reaction?

Are there any chemicals or materials that can absorb Methane as well as CO_2?

- Methane in another greenhouse gas largely contributing to climate change

What other chemicals or materials can absorb CO_2, are these more effective than triethanolamine?

- Lithium hydroxide has been used on spaceships to remove CO_2 (Nasa, n.d.)
- Metal Organic Frameworks (MOFs) have shown promising absorption properties because of their massive surface area(Aniruddha, 2020)
- Zeolites have shown success in absorption of CO_2 (Kumar, 2020)

How effectively does the triethanolamine release the CO_2?

- This is important so that the carbon can be discarded of in a way that it won't continue to harm the environment

Does triethanolamine have cyclic abilities?

- When looking for a material for CO_2 capture, ideally it would be cyclable so that it can absorb the CO_2 and release it, repeatedly.

What is the most effective way to discard of the CO_2 so that it is no longer harming the environment?

- Current ideas include carbon sequestration, an example of this is burying the CO_2 underground in saline aquifers(Roberts, 2019) or making the CO_2 into a product, some examples of this include carbonated drinks, plastic, concreate (PSBO News, 2021)

What is the most effective technique to use for CO_2 scrubbing?

- Some current techniques include using a high shear jet absorber(Chakma, N.D.)
- The stir and fan method is where the contents of canisters of lithium hydroxide are dispersed into horizontal surfaces. This is an older method currently being improved on as it releases large volumes of caustic lithium hydroxide dust(Norfleet, n.d.)

The greater the volume of amines, the faster the CO_2 was absorbed. Therefore, the hypothesis was supported.

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Log Book

CARBON CAPTURE

COULD THIS BE HOW WE SAVE THE PLANET?

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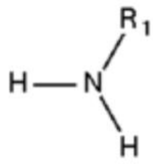
Some Notes:

These notes were taken throughout the course of the investigation. Bibliography is included at the end of the report.

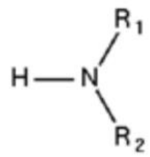
Amines Research

https://courses.lumenlearning.com/suny-potsdam-organicchemistry2/chapter/23-1-properties-of-amines/#:~:text=Amines%20are%20organic%20compounds%20which%20contain%20and%20are%20often%20actually,or%20more%20atoms%20of%20nitrogen.&text=In%20an%20amine%2C%20one%20or,aryl%20(aromatic%20ring)%20groups

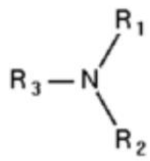
- Amines are organic compounds which contain and are often based around one or more atoms of nitrogen
- Nitrogen can bond up to 3 hydrogens
- One or more of the hydrogen atoms from ammonia are replaced by organic substituents like alkyl (alkane chain) group and Aryl (aromatic ring) group
    - An alkyl group is an alkane with hydrogen atom missing from its chain, can be a simple, branched or cyclic chain, does not have aromatic rings. Only have carbon and hydrogen atoms on structure
    - An aryl group contains an aromatic ring. It is a simple aromatic compound with one hydrogen atom missing, the missing hydrogen atom allows it to get attached to a carbon chain.
- Amines can be either primary, secondary or tertiary depending on the number of carbon containing groups attached
    - if there is only one carbon containing group then the amine is primary
    - if there is 2 carbon containing groups then the amine is secondary
    - if there are 3 carbon containing croups the amine is tertiary
- boiling point of amines is higher than corresponding phosphines (compounds containing phosphines) but is generally lower than corresponding alcohols



Primary Amine



Secondary Amine



Tertiary Amine

Triethanolamine

https://thechemco.com/chemical/triethanolamine/

- oily, viscous chemical
- tertiary amine
- triol (a molecule with three alcohol groups)
- bifunctional compound that exhibits both properties of alcohols and amines

https://www.vox.com/energy-and-environment/2019/9/4/20829431/climate-change-carbon-capture-utilization-sequestration-ccu-ccs

(Roberts, 2019)

- scientists estimate that to hold the rise in global average temperature at 1.5 degrees celcius above the preindustrial baseline, which is considered a safe level of warming, humans must stabilise the atmospheric concentration of CO_2 at around 350 PPM
- there is already too much CO_2 in the atmosphere so to allow for a secure climate for future generations we don't need to just reduce emissions, we have to remove co2 from the atmosphere
- almost every model used by the international panel on climate change (IPCC) shows reaching a safe climate involves negative emissions
- one way to help reach negative emissions is pull CO_2 out of the air and bury it underground in saline aquifers
- A 2017 paper in Nature Climate Change estimates the total amount of emissions that need to be avoided between now and 2050 to stay under 2 degrees — at 800 gigatons. The paper estimates that even if emission reductions are successful, between 120–160 gigatons will need to be sequestered during that period.

https://www.co2.earth/daily-co2
(CO2.earth, 2021)
- on the 17th of July 2020 the atmospheric CO_2 reading was 414.43 ppm
- on the 17th of July 2021 (latest reading) the atmospheric CO_2 reading was 418.87 ppm
- the above stats show a 4.44 ppm (1.07%)increase in atmospheric CO_2 since last year

https://www.sciencedirect.com/science/article/abs/pii/0950421489850030
(chakma, N.D.)
- study using a high shear jet absorber to distribute fine droplets of a aqueous triethanolamine solution to absorb CO_2
- the CO_2 was absorbed rapidly

https://courses.lumenlearning.com/introchem/chapter/factors-that-affect-reaction-rate/
(lumen, N.D.)
- when concentration is increased, the reaction proceeds more quickly as there is an increase in the number of molecules that have the minimum required energy
- in gasses increasing pressure has the same effect as increasing concentration
- rising the temperature of the reaction can double or triple the reaction rate, this is due to an increase in the number of particles that have the minimum energy required, a decrease in temperature will decrease the reaction rate. The minimum energy needed to undergo a reactionstays the same with increasing temperature. However, the average increase in particle kinetic energy caused by heat means more particles have the minimum energy necessary
- for a reaction to occur there must be a certain number of molecule with energies equal to or grater than the activation energy

https://www.education.vic.gov.au/school/teachers/teachingresources/discipline/science/continuum/Pages/chemreactions.aspx

(Victoria state government, 2020)

- chamical reactions involve interaction between chemicals where all reactacnts are changed into new materials
- chamical reactions involve breaking chemical bonds between the reactant molecules and forming new bonds between atoms in product molecules.
- The number of atoms before and after the chemical change is the same but the number of molecules will change

https://www.middleschoolchemistry.com/lessonplans/chapter6/lesson1
(American Chemical Society, 2021)

- In a chemical reaction the atoms and molecules that interact with each other are called reactants
- In a chemical reaction the atoms and molecules produced by the reaction are called products
- Only the atoms present in the reactants can end up in the products, no new atoms are created and no atoms are destroyed
- Reactants contact each other, bonds between atoms are broken and atoms rearrange to form new bonds to make the product
-

https://www.pbs.org/newshour/science/would-you-use-products-made-of-recycled-carbon-dioxide
(PSBO News, 2021)

- Carbonated drinks, plastic, concreate can be made out of recycled CO2

https://www.britannica.com/science/chemical-reaction

- A chemical reaction is a process where one or more substances, the reactants, are converted into one or more different substances, the products
- A chemical rection rearranges the atoms of the reactants to create different substances as products

https://pubmed.ncbi.nlm.nih.gov/14632003/
(Norfleet, n.d.)

- Stir and fan method where the contents of canisters of lithium hydroxide are dispersed into horizontal surfaces

https://www.sciencedirect.com/science/article/abs/pii/S2212982020303863
(kumar, 2020)

- Successful study using Zeolites

https://www.sciencedirect.com/science/article/abs/pii/S2212982020306338
(Aniruddha, 2020)

- Study using MOFs for CO2 capture

https://www.nasa.gov/pdf/519347main_AP_ST_CO2Removal_Therm.pdf
(Nasa, n.d.)

- Lithium hydroxide has been used for CO2 scrubbing in spaceships

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6470649/
https://aip.scitation.org/doi/pdf/10.1063/1.4992908

- Shows effect of pH on CO2 absorption

https://climate.nasa.gov/effects/#:~:text=The%20potential%20future%20effects%20of,and%20intensity%20of%20tropical%20storms.
(Nasa, n.d.)

- Global climate change has already had an observable effect on the environment
- Glaciers have shrunk, ice on rivers and lakes is breaking earlier, plant and animal ranges have shifted, longer and more intense heatwaves
- Future effects, temperatures will continue to rise, more severe droughts and heatwaves, more frequent wildfires, an increase in the number, duration and intensity of tropical storms and hurricanes, the sea level will rise 1-8 feet by 2100 and it is expected that before 2050 we will have an ice free arctic.

https://www.worldwildlife.org/stories/our-planet-is-warming-here-s-what-s-at-stake-if-we-don-t-act-now
(WWF, n.d.)

- Sea levels will rise, by 2100 70-100% of all coral reefs will be bleached, Ice free artic, Heat waves flooding, plants and animals will lose more habitat causing more species to go extinct

https://climate.nasa.gov/causes/
(nasa, n.d.)

- Scientists attribute the global warming trend to the human expansion of the greenhouse effect
- Certain gasses in the atmosphere block heat from escaping
- The gasses that contribute to the greenhouse effect are water vapour, nitrous oxide, carbon dioxide(CO2) and Methane
- Water vapour acts as a feedback to the climate
- Humans have drastically increased CO2, methane, nitrous oxide
- Human activities are changing the natural greenhouse, burning fossil fuels has increased the concentration of atmospheric CO2.
- Clearing land has also increased concentrations of greenhouse gasses

5/5 – 29/5
I read through many websites looking at research and experiments based on carbon capture and utilisation technology. During this research I was looking at carbon capture very generally to find techniques/chemicals/materials/etc. that have shown some potential for use in carbon capture technology and could be accessible for me to use in my experiment.

29/5
Throughout my research I have found that a group of chemicals called amines have shown some potential in carbon capture technology.

31/5
Talked to school laboratory technicians about the possibility of sourcing amines (a group of compounds that I had found had shown some capacity for usage in carbon capture technology throughout my research) for use in my experiment.

2/5
The school lab technicians gave me Triethanolamine for use in my experiment.

6/6
I wrote a method and a materials list for a potential experiment where the variable is temperature.

Materials:
- Triethanolamine
- A water bath
- A bubbler, sealed environment
- CO2 probe and laptop

Method:
1. the water bath was filled with water
2. the temperature of the water bath was set to 20 degrees Celsius and allowed to heat up
3. the bubbler was set up
4. The CO2 probe was set up
5. 75ml of triethanolamine was poured into the container
6. The stopper was sealed so that it was airtight
7. The container was placed into the water bath once the water bath had reached the correct temperature and the bubbler was started
8. After 10 hours the container was removed from the water bath and the results were collected from the probe and computer
9. Repeat steps 1-8 having the water bath set to 40°C, 60°C, 80°C and 100°C

7/6
Today I talked to the laboratory technicians about finding a way to bubble the air through the Triethanolamine. The only bubbler that the school had was one from an aquarium, this

would not work as it would introduce air outside, this would not allow for the CO_2 levels to be measured. Because of this, magnetic stirrers will have to be used instead.

8/6

I performed a trial experiment following the method and material list below, before this experiment was held, my science teacher helped me do a risk assessment and clear the chemical for usage.

Materials:

- 20ml of Triethanolamine
- CO_2 probe and container
- Magnetic stirrer and large magnetic flea
- A measuring cylinder
- A laptop

Method:

1. A new file was set up on spark view on a laptop
2. The CO_2 probe was connected to the laptop
3. 20 ml of Triethanolamine was measured using a measuring cylinder
4. 20 ml of Triethanolamine was poured from the measuring cylinder into the container
5. A magnetic flea was added to the container
6. The container was placed on a magnetic stirrer
7. The probe was calibrated
8. The magnetic stirrer was set to speed 500
9. The probe was put in the container, the stopper sealing the container
10. The graph was started
11. The results were collected after 19.5 hours

When performing this trial experiment, the CO_2 was initially absorbed much faster than expected dropping from 400 ppm to 80 ppm in less than 4 minutes.

9/6

Today I collected the results from the trial experiment set up yesterday.
In the results, there was lots of fluctuation in the CO_2 levels and they increased drastically twice over the course of the experiment, this shows that there was an error. It has been assumed that when the CO_2 was absorbed, pressure was created inside of the bottle and that this caused for air to be sucked past the probe and stopper, that were not secured properly. This caused the CO_2 levels to rise and the reaction to take place again.

Today I held another trial experiment. During this experiment, I took extra care to make sure that the stopper was secured properly, the CO_2 probe and the stopper are two separate pieces with the probe passing through the stopper. I think this was loose in the last experiment, contributing to the error. Before this experiment I took apart the two pieces, cleaned in between them and secured then more tightly. The method for this experiment is written below.

Method:

1. A new file was set up on spark view on a laptop
2. The CO2 probe was connected to the laptop
3. The CO2 probe was calibrated
4. 20 ml of Triethanolamine was measured using a measuring cylinder
5. 20 ml of Triethanolamine was poured from the measuring cylinder into the container
6. The container was sealed using the probe and stopper
7. the probe and the bottle were taped together
8. The results were collected after 20 hours

In this experiment, the CO2 levels decreased very quickly from around 400 ppm to 0 ppm in less than 30 seconds. The levels stayed at 0 for the rest of the time. This confirms that there was an error in the last experiment.

10/6

Because the last experiment progressed so quickly the new variable is going to be volume of amines, I will also use a lower volume to start with to slow down the reaction. I am also going to perform an experiment varying temperature to see if the amines release the CO2 and if they absorb quicker at lower temperatures.

A stirrer will also not be used in the experiment as the reaction was so fast.

14/6

Today I wrote a method for an experiment varying the volume of Triethanolamine:

Independent variable: volume of Triethanolamine
Dependant variable: the time it takes for the CO2 concentration to reach 0 ppm

1. A new file was set up on spark view on a laptop
2. The CO2 probe was connected to the laptop
3. The CO2 probe was calibrated
4. 30 seconds was taken to measure the correct volume of Triethanolamine (1ml, 5ml, 10ml, 15ml, 20ml) using a measuring cylinder
5. 1 minute was taken to pour the triethanolamine from the measuring cylinder into the container and the container was prepared for the probe to be attached
6. As soon as the minute ended the probe was secured into the container and the container was sealed with the stopper, the graph was started
7. The graph was stopped after the CO2 concentration reached a stable level of 0
8. The time was calculated from when the graph first started to the first point when the CO2 concentration reached 0 ppm.
9. Repeat steps 1-8 for all concentrations of amines

In this method I have set times to do the steps that involve transferring the amines from the bottle to the container. This is to try to control the variable of having the amines exposed to air before being sealed, this is important to try to control as the amines will absorb CO2 from the air when being transferred and if one is sitting in the air longer than another, it may affect the results as it has absorbed more carbon.

16/6
I have been trying to find time to perform experiments however, I need to be supervised so I have been unable to find time.

17/6
Today I wrote a method for a secondary experiment, varying temperature.

1. A new file was set up on spark view on a laptop
2. The CO_2 probe was connected to the laptop
3. The CO_2 probe was calibrated
4. 30 seconds was taken to measure the correct volume of Triethanolamine (1ml, 5ml, 10ml, 15ml, 20ml) using a measuring cylinder
5. 1 minute was taken to pour the triethanolamine from the measuring cylinder into the container and the container was prepared for the probe to be attached
6. As soon as the minute ended the probe was secured into the container and the container was sealed with the stopper, the graph was started
7. A water bath was heated to 85°C
8. 2 hours after the graph was started, the container was placed into the water bath
9. 2 hours after the container was placed into the water bath, the container was removed from the water bath
10. 2 hours after the container was removed from the water bath, the container was placed into an ice bath at ???°C
11. 2 hours after the container was placed into the ice bath, the container was removed from the ice bath
12. 2 hours after the container was removed from the ice bath, the container was placed back into the water bath at 85°C
13. 2 hours after the container was placed into the water bath, the graph was stopped and the results were collected

18/6
Today I performed an experiment following the method below.

Independent variable: Volume of Triethanolamine
Dependant variable: The time it takes for the CO_2 concentration to reach 0 ppm

1. A new file was set up on spark view on a laptop
2. The CO_2 probe was connected to the laptop
3. The container was stuck to the surface it was sitting on using sticky tape
4. The CO_2 probe was calibrated
5. The bottle cap was taken off of the bottle of Triethanolamine and the stopwatch was started
6. 2 minutes were taken to measure the correct volume of Triethanolamine (1ml, 5ml, 10ml, 15ml, 20ml) using a measuring cylinder
7. 1 minute was taken to pour the triethanolamine measured from the measuring cylinder into the container and the container was prepared for the probe to be attached

8. As soon as the minute ended the probe was secured in the container and was sealed using the stopper, the graph was started
9. The graph was stopped after the CO2 concentration reached a stable level of 0 without rising
10. The graph was downloaded onto a USB
11. The CO2 probe was removed from the container
12. The stopper was removed from the probe and was cleaned
13. The stopper was cleaned
14. The stopper was connected back onto the probe
15. The container was rinsed and dried
16. The measuring cylinder was rinsed and dried
17. Repeat steps 1-15 for all concentrations of amines (1ml, 5ml, 10ml, 15ml, 20ml)

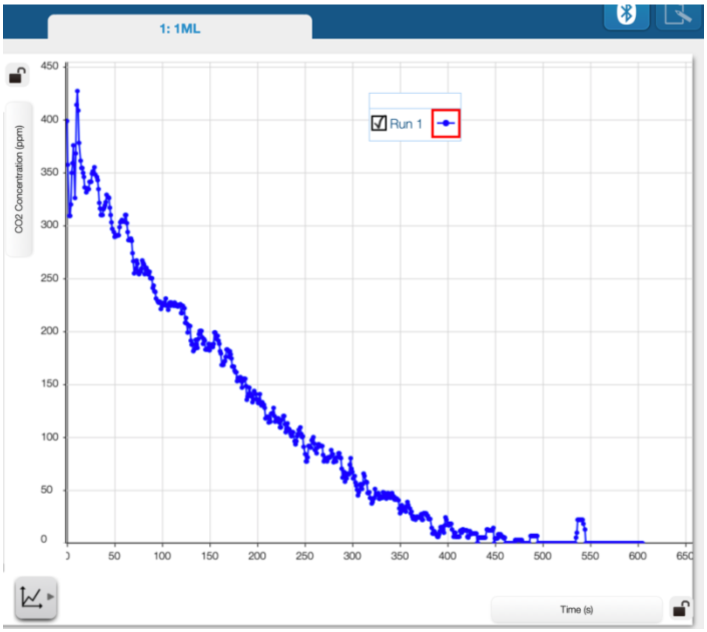
The probe and container were sitting on top of the magnetic stirrer, the magnetic stirrer was not on, it was only used to stick the container to so that it would not fall over when the probe was attached. A 50 ml measuring cylinder was used for volumes, 20 ml, 15 ml and 10 ml. A 10 ml measuring cylinder was used for volumes 5ml and 1 ml.

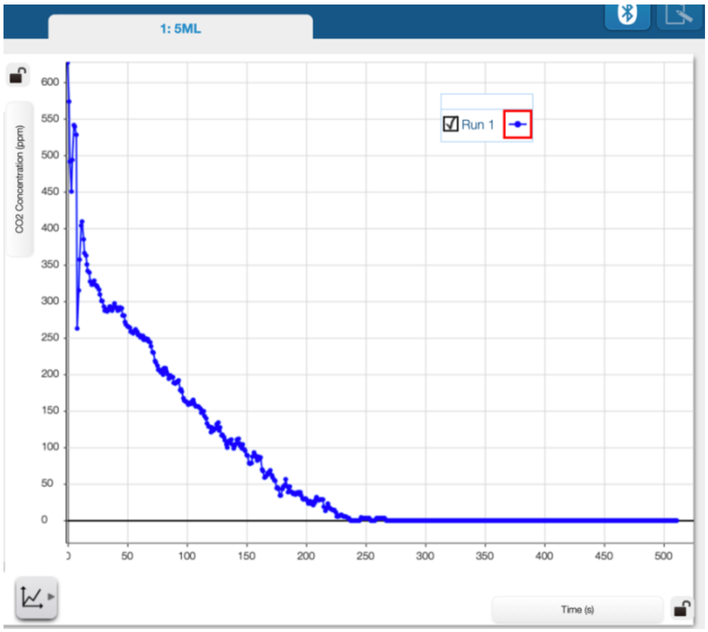
19/8

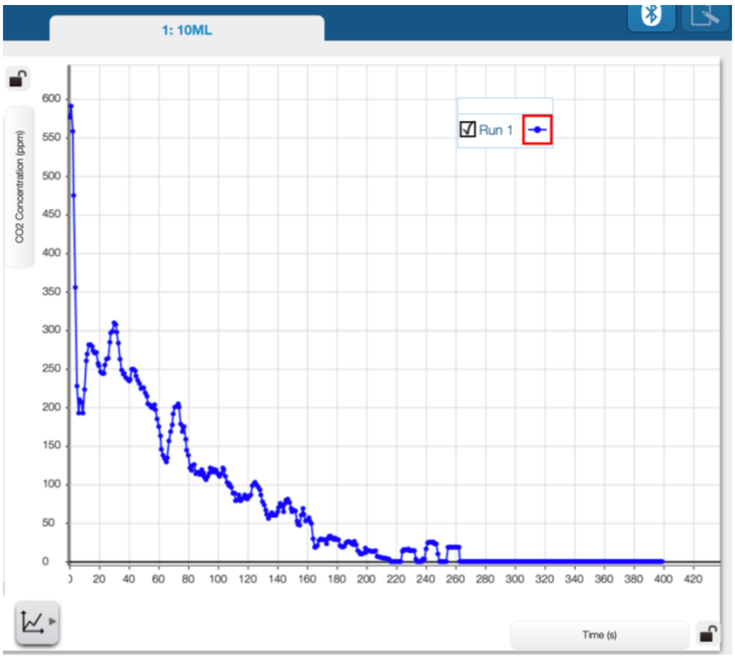
When looking at the results I noticed that the surface area that the Triethanolamine is covering makes a significant difference in the results. In my second trial experiment I had the container laying on its side with 20ml of Triethanolamine covering the whole side of the container, in a later experiment I had the container vertical with 20ml of Triethanolamine covering the base. The surface area of the side was much larger than the base. In the experiment where the amines are covering a larger surface area it took much less time for the CO2 concentration to reach 0PPM. When the container was laying on its side with the amines covering a much larger surface area, the CO2 concentration reached 0 in just 21 seconds whereas it took 139 seconds when the container was upright, and the amines were covering a much smaller surface area. Therefore, a conclusion can be drawn that the larger the surface area that the amines are covering, the quicker the CO2 concentration will reach 0PPM.

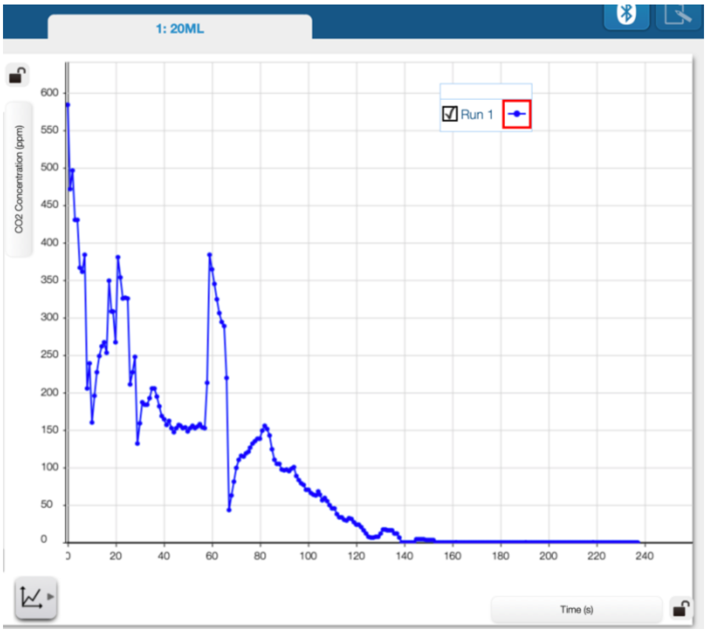
Results

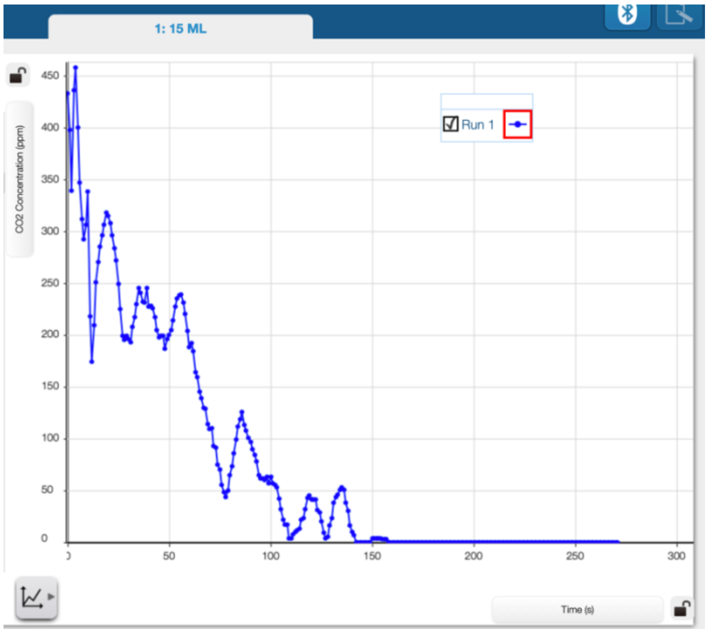
Volume of amines (ml)	time taken for CO2 concentration to reach 0 PPM (seconds)
1	431
5	237
10	216
15	142
20	139











Selected/Shortened Data

The Effect of the Volume of Amines on the Time it Takes for the CO_2 Concentration to Reach 0PPM

Time (s)	Volume of Triethanolamine				
	20 ml	15ml	10ml	5ml	1ml
0	584	433	577	627	399
10	160	338	223	357	414
20	267	315	254	323	331
30	159	196	310	293	348
40	164	227	234	292	319
50	148	200	225	266	289
60	364	188	175	254	304
70	99	109	192	238	266
80	138	65	138	200	265
90	96	97	115	187	241
100	70	63	114	162	224
110	45	4	89	155	227
120	24	41	81	121	217
130	12	23	78	117	191
139	0				
140		10	65	102	200
142		0			
150			65	90	182
160			54	87	188
170			28	69	176
180			29	43	156
190			23	37	138
200			12	30	135
210			6	28	119

216			0		
220				16	116
230				7	105
237				0	
240					93
250					84
260					94
270					77
280					76
290					62
300					67
310					51
320					37
330					44
340					43
350					28
360					33
370					24
380					23
390					6
400					18
410					6
420					12
430					9
431					0

Raw data

The Effect of the Volume of Amines on the Time it Takes for the CO_2 Concentration to Reach 0PPM

Time (s)	Volume of Triethanolamine				
	20 ml	15ml	10ml	5ml	1ml
0	584	433	577	627	399
1	472	398	591	574	357
2	496	339	558	491	309
3	430	436	475	450	309
4	430	458	356	494	320
5	367	400	228	541	350
6	361	347	193	539	359
7	384	312	210	528	376
8	206	292	207	263	326
9	239	306	193	315	368
10	160	338	223	357	414
11	196	218	260	404	427
12	227	174	269	409	409
13	249	209	281	385	378
14	262	251	281	366	361
15	267	270	279	363	354
16	253	285	274	351	354
17	349	296	270	342	350
18	308	306	271	339	346
19	308	318	257	327	336
20	267	315	254	323	331
21	381	308	246	325	335
22	354	296	244	328	334
23	326	284	244	323	334
24	327	272	255	322	341
25	326	249	263	319	341
26	211	225	264	316	349
27	227	199	285	309	351
28	248	195	297	300	350
29	132	199	299	300	355
30	159	196	310	293	348
31	187	193	308	287	346
32	184	208	298	289	343
33	184	217	284	286	334
34	193	230	263	288	321
35	205	245	248	293	316
36	205	241	243	293	310

37	195	232	244	287	310
38	182	231	239	292	315
39	169	245	236	297	317
40	164	227	234	292	319
41	157	228	236	292	322
42	162	226	249	287	329
43	152	217	250	288	327
44	147	205	247	292	326
45	152	198	241	290	317
46	157	199	235	280	310
47	156	199	231	280	303
48	153	187	224	272	297
49	154	196	225	268	294
50	148	200	225	266	289
51	153	205	219	265	291
52	156	214	214	264	290
53	152	227	205	258	291
54	155	235	204	258	291
55	158	238	200	256	298
56	154	239	199	259	303
57	153	231	204	262	304
58	213	220	197	258	305
59	384	204	185	254	304
60	364	188	175	254	304
61	345	192	163	251	310
62	324	184	146	252	310
63	306	164	138	253	302
64	294	159	134	247	294
65	289	145	129	250	286
66	220	139	135	247	287
67	43	130	156	248	288
68	63	129	169	245	285
69	81	114	177	244	274
70	99	109	192	238	266
71	110	110	200	231	255
72	116	93	201	230	259
73	115	91	205	218	267
74	119	75	200	216	264
75	121	70	178	212	256
76	127	55	168	206	254
77	132	48	175	206	256
78	135	44	159	203	259

79	138	50	145	204	267
80	138	65	138	200	265
81	149	73	122	208	263
82	156	86	118	208	254
83	151	99	125	204	260
84	143	112	126	200	258
85	124	119	114	194	254
86	110	126	116	198	254
87	105	113	115	196	256
88	105	108	113	196	250
89	97	101	119	188	250
90	96	97	115	187	241
91	97	90	109	189	243
92	95	84	106	189	238
93	98	78	110	192	237
94	101	65	115	178	231
95	89	62	121	179	229
96	83	62	120	176	227
97	79	60	116	167	227
98	77	63	119	164	228
99	70	57	118	163	221
100	70	63	114	162	224
101	66	57	110	158	225
102	64	55	114	161	227
103	63	53	121	162	225
104	68	42	119	159	231
105	64	32	111	165	224
106	56	22	103	161	220
107	59	17	99	156	226
108	55	17	101	156	227
109	50	4	96	156	224
110	45	4	89	155	227
111	45	8	89	153	225
112	38	10	79	147	224
113	34	12	80	149	227
114	34	13	87	150	226
115	30	22	79	143	224
116	29	23	81	140	225
117	32	32	82	133	223
118	31	43	86	129	225
119	27	45	84	128	226
120	24	41	81	121	217

121	24	41	84	127	217
122	21	41	87	123	224
123	16	31	98	125	222
124	12	29	101	126	208
125	8	20	103	132	213
126	6	9	100	134	207
127	6	4	96	123	199
128	8	5	93	127	206
129	8	16	86	116	205
130	12	23	78	117	191
131	17	38	73	114	187
132	17	44	67	110	188
133	16	46	61	104	181
134	16	51	56	100	183
135	16	53	60	106	192
136	12	51	64	110	187
137	12	38	60	111	184
138	6	30	60	104	193
139	0	16	60	99	197
140		10	65	102	200
141		7	70	105	200
142		0	76	111	194
143			72	112	188
144			65	105	193
145			75	102	191
146			80	99	183
147			81	104	183
148			77	97	184
149			69	95	188
150			65	90	182
151			67	88	186
152			66	78	187
153			52	77	185
154			48	78	188
155			47	87	199
156			60	93	199
157			69	90	193
158			61	86	196
159			53	82	191
160			54	87	188
161			57	84	181
162			52	86	179

163			49	70	168
164			30	67	168
165			19	59	171
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167			21	62	176
168			27	65	183
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172			28	59	178
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203			13	26	141
204			13	23	130

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207			7	24	131
208			7	29	128
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211			4	27	119
212			4	29	114
213			4	29	118
214			3	28	115
215			3	18	122
216			0	13	123
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