Advanced Visual CO_2 Sensor For Space Habitation

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Project Overview

Monitoring CO_2 levels in space habitation is crucial for astronaut safety. The upper bound for regular CO_2 levels in a room is 1000ppm (0.1%). 5000ppm (0.5%) is the upper bound for loss of attention, increased heart rate, nausea, headaches, and sleepiness. Any concentration greater than 40,000ppm (4%) leads to death or serious brain damage. Human breath consists of about 4% CO_2.

Current methods employ expensive electronics that take up valuable storage space and must be monitored, so storage and cost is an issue in space habitation. We propose to develop a less expensive, more convenient, and long lasting CO_2 color-changing coating that changes color in increasing levels of CO_2 which takes up virtually no storage.

We hope to see the coating in paints or on wearables such as bracelets and clothing so astronauts will be alerted earlier by seeing a color change on their person instead of constantly monitoring electrical equipment.

Variables / Equations

Glycerol

- Plasticizer used to make polymers softer. Glycerol in the coating helps retain water for the CO_2 acid-base reaction.
- Used as sweetener, food preservative, or as lubricants.

Base

- Sodium bicarbonate (SB) is a weak base, carbonic acid buffer, and makes the color change reversible.
- TBAH is a strong base and is an alternative base to sodium bicarbonate.

Indicator

- Acid-base indicator used for color change in a pH range.
- Ideally pKa of indicator should match pH of base for quick color change and increased sensitivity.

Carbonic Anhydrase

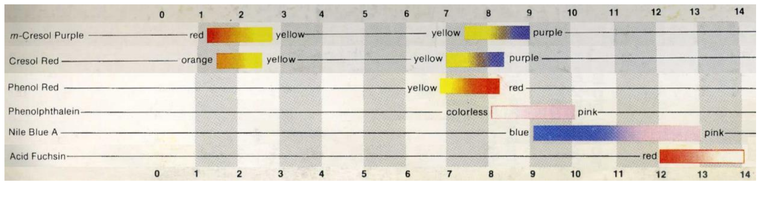
- One of the most important enzymes in the human body.
- Catalyzes the reaction of CO_2 in water to form acid which is transported from red blood cells to the lungs and then reversed back to CO_2 to be released when exhaling.

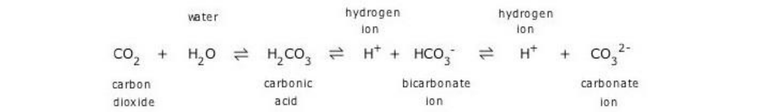
Albumin Protein

- Albumin is the main protein found in chicken egg whites.
- Promotes diffusion of CO_2 through aqueous solutions.
- Albumin is in human blood and acts as a carrier for the transport of ions, vitamins, and enzymes.

Other

- HEC Polymer – cosmetics, compatibility
- Coating thickness – thin gives greater diffusion.
- Pressure – limiting agent. Fractions of an atmosphere.
- Humidity – moisture improves sensitivity.
- Hydrophobic solvent – like dissolves like.





$C = kP_{gas}$

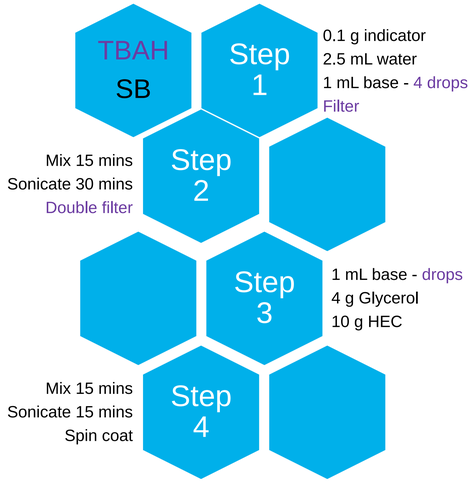
- C is the solubility of a gas at a fixed temperature in a particular solvent (in units of M or mL gas/L)
- k is Henry's law constant (often in units of M/atm)
- P_{gas} is the partial pressure of the gas (often in units of atm)

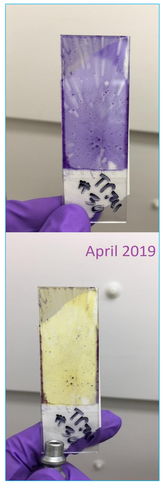
Materials/Procedure

Materials (Trial #8)	Quantity
Carbonic Anhydrase	0.04 g
Store Bought Egg Whites	None
Glycerol	4.18 g
Sodium Bicarbonate (0.6M)	2.0 mL

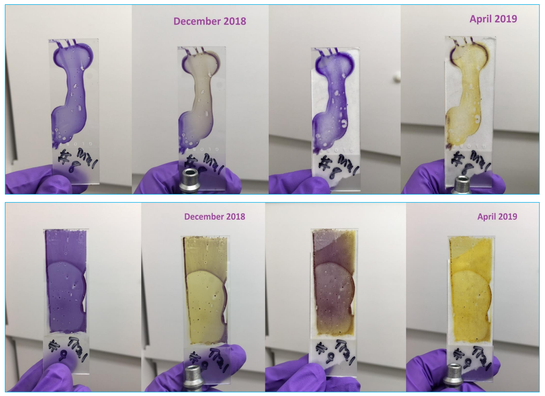
Materials (Trial #9)	Quantity
Carbonic Anhydrase	0.036 g
Store Bought Egg Whites	2.5 mL
Glycerol	4.08 9
Sodium Bicarbonate (0.6M)	2.0 mL

Materials (Trial #30)	Quantity
Carbonic Anhydrase	0.030 g
Albumin Powder	0.007 g
Glycerol	3.67 9
TBAH (0.1M)	0.7 mL (14 drops)





Results



- Trial #8 using sodium bicarbonate is responsive to gas and not breath. Slower recovery time than initial trials. Enzyme but no protein. Little change 4 months later.
- Trial #9 using sodium bicarbonate shows sensitivity and color change from breath. Slower recovery time than initial trials. Enzyme and protein. Breath effect stops after 1 week. Discoloration and breath effect failure due to perishable egg whites, still shows good responsiveness 4 months later.
- Trial #30 using TBAH and albumin powder is slightly less responsive than trial #9 and slightly greater recovery time. Is responsive to breath, but takes more exhaling. Less water in coating than trials #8 and #9 due to TBAH drops. Ongoing study for breath effect lifetime.

Conclusion

- Trials showed improved sensitivity when using albumin and carbonic anhydrase at higher levels of glycerol. Glycerol softens the polymer and increases hydration allowing for greater diffusion of CO_2.
- High glycerol levels impair use as solid coating due to a greater liquid phase than solid phase. More study is needed to perfect solid to liquid phase ratios.
- Limited CO_2 pressures, buffers, low humidity, and a less hydrophobic medium contribute to decreased sensitivity. Alcohol based solvents or heat destroy and inhibit the enzyme and protein activity.
- Options for increasing sensitivity include changing indicator to transition in near neutral pH to add less base. Greater enzyme or protein quantities, more hydrophobic solvents, polymers or plasticizers, and switching bases.

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Works Cited

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