Diffusion of gases

Comparing gases with different molecular masses

In the book[1], Microscale activity 3.2 demonstrated how chorine gas diffuses from a point source to occupy all the space in the Petri dish. Here is a similar experiment but, this time, using ammonia so that the speed at which the gases travel can be compared. Ammonia moves more rapidly than chlorine because it has a lower molecular mass. This can be carried out in the Petri dish as in the original activity, but it is so rapid that students might not be convinced to the diffusion effect.

To observe the faster diffusion of ammonia in air[2], a larger surface area is required. A cover is required to protect the gas from draughts and the student from the odour of the gas. An inverted plastic transparent food container can be used.

Box 1: The Maxwell Boltzmann curve

The distribution of the speeds of molecules in a gas is presented graphically using Maxwell-Boltzmann distribution curves.

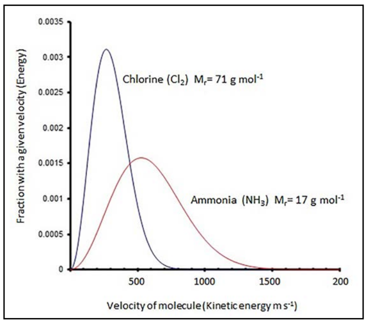

Figure 1: The distribution of the velocities of ammonia and chlorine at room temperature. At the same temperature, the gases, no matter what they are, have the same kinetic energy

The shape is not symmetrical around the highest speed (as in Gaussian curves). The mean (average speed) is to the right of the maximum value (the mode).

Outline requirements

- eye protection
- paper towel
- 500 or 1000 cm^3 plastic container. Measure the dimensions of the container. (Lid not required).
- Prepare a template based on the idea in Figure 2. The dimensions should accommodate those of the food container.
- dropper bottles or transfer pipettes of:
  - 0.2 M ammonia
  - 'Distilled water' with an indicator such as universal indicator, phenolphthalein or bromothymol blue.
- Access to a visualiser to project the event as a demonstration

Outline method (see Figure 3 overleaf)

1. Insert the grid into a plastic wallet.
2. Place one drop each of the indicator solution onto each of the white circles.
3. Place an empty medical blister pack on the orange ellipse.
4. Add 5-10 drops of 2 M ammonia solution into the blister pack.
5. Quickly place the microwave or plastic container over the top of the drops to remove the effects of draughts.
6. What happens to the indicators?
7. (Optional) Photograph the appearance of the drops at various time intervals (Figure 3).
8. Disposal: Remove the cover, waft your hand over the top to disperse the ammonia gas and wipe over the plastic surface with damp paper towel.

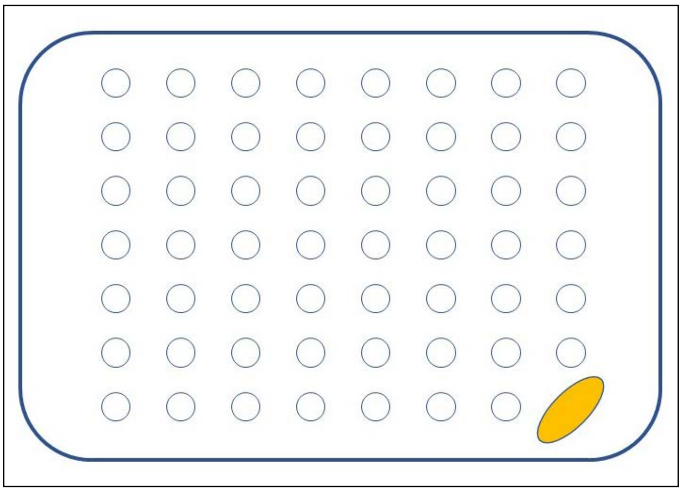

Figure 2: Template

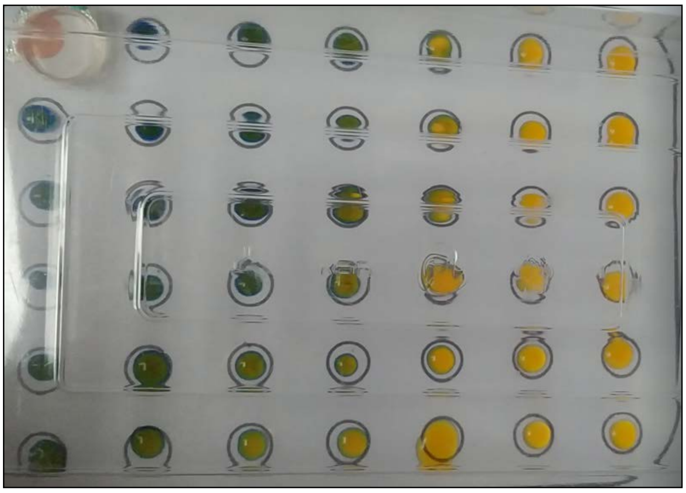

Figure 3: Diffusion of ammonia

A Visual Method of Observing the Diffusion of Ammonia and Hydrogen Chloride

Microscale activity 3.3 is a microscale version of the classic long tube demonstration. The following version is a more visual demonstration of the chemistry, which makes use of a damp strip of universal indicator paper. This illustrates the path of the acid hydrogen chloride and the alkaline ammonia[3].

At a constant temperature for 2 different gases:

$$KE_{ammonia} = KE_{hydogen\ chloride} = \frac{1}{2}m_{ammonia}v_{ammonia}^2 = \frac{1}{2}m_{hydogen\ chloride}v_{hydogen\ chloride}^2$$

$$\frac{m_{ammonia}}{m_{hydogen\ chloride}} = \frac{v_{hydogen\ chloride}^2}{v_{ammonia}^2}$$

but velocity (v) is the distance(s) travelled in a certain time (t), and time is the same for both gases.

$$\frac{m_{ammonia}}{m_{hydogen\ chloride}} = \frac{v_{hydogen\ chloride}^2}{v_{ammonia}^2} = \frac{s_{hydogen\ chloride}^2}{s_{ammonia}^2}$$

The distances that the two gases travel in the tube or, in the case to follow, in the Petri dish are related to the square root of the molar mass of the gases.

$$\frac{s_{hydogen\ chloride}}{s_{ammonia}} = \sqrt{\frac{m_{ammonia}}{m_{hydogen\ chloride}}} = \sqrt{\frac{17}{36.5}} = 0.68$$

The result of the diffusion in the Petri dish is shown in Figure 4. An orange line is placed at the calculated ratio. The colour of the universal indicator paper at that point is orange but the pH of ammonium chloride. The salts of weak acids such as ethanoic acid or cabonic acid are alkaline in solution. The salts of weak bases such as ammonia are acidic.

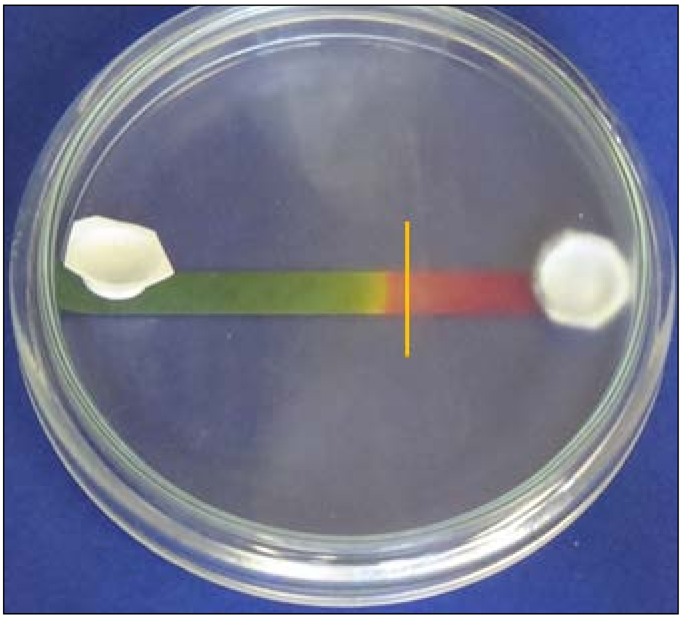

Figure 4: The Visual diffusion in a Petri Dish

Outline requirements

- eye protection
- 9 cm diameter glass Petri dish (Glass is a better material than plastic for this activity)
- 9 cm strip of universal indicator paper (the version on the reel is best although the shorter test papers can be used)
- 2 small, empty medical blister packs
- a dropper bottle of 2 M ammonia solution
- 1 cm^3 of concentrated hydrochloric acid* in a closed dropper bottle that students could use (a few of these could be passed around the class with careful monitoring by the teacher)
- paper towel
- white card
- bowl of water

*The presence of even 1 cm^3 of concentrated acid may create the need to move this activity to a demonstration on a visualiser and projected (via a webcam) to a screen.

Outline method

1. Place the Petri dish on the white card.
2. Place 9 cm of universal indicator paper over the yellow strip and add drops of tap water to the strip to just dampen it.
3. The two blister packs are placed at either end of the pH paper.
4. With a colleague, add 1 drop of concentrated hydrochloric acid to one blister pack and 1 drop of 2 M ammonia to the other blister pack at the same time. Immediately put the lid on the Petri dish.
5. Record/photograph/project the result on onto a screen. The results last for some time.
6. Disposal: Lower the Petri dish into a bowl of water.

Teacher activities

Carry out Microscale activity 3.3 in the book and apply the ratios of the distances the two gases travel with square root to their molar masses as in Equation 1.

Teachers or students can construct a series of cartoons akin to Figure 3.3 in the book showing how the gases molecules behave in travelling along the tubes and then reacting to form ammonium chloride.

Try diffusion in 3 dimensions

Use the diagram below for guidance. This diagram shows the arrangement for ammonia diffusion. Gases lighter than air (e.g. ammonia) rise to the top and then proceed to occupy the whole container. Gases heavier than air (e.g. hydrogen chloride and chlorine fall to the bottom and then proceed to occupy the whole container.

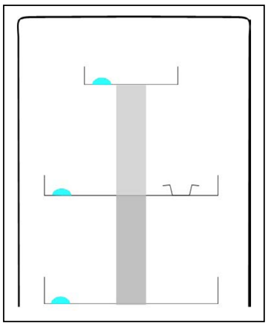

Figure 5: Diagrammatic design of the arrangement

Two 9 cm diameter plastic Petri dishes and a smaller Petri dish are connected with plastic vials, stuck together using Blu-tak®. This structure is placed on a tray.

Drops of bromothymol blue indicator in distilled water are placed on the Petri dishes. There is a blister pack on the middle tier to which 2 M ammonia will be added.

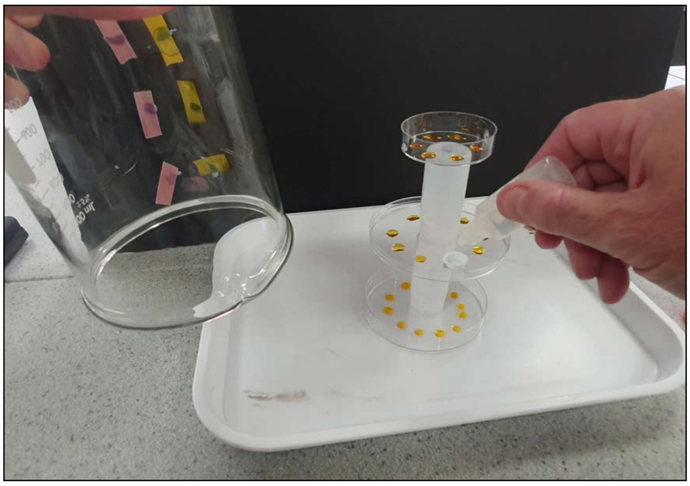

Figure 6: Placing the beaker over the cake stand arrangement

Litmus and/or pH indicator strips are stuck on the sides of a 1 litre beaker with Blu-tac® and made damp with distilled water.

More than 5 drops of 2-3 M ammonia is added to the blister pack.

The 1 litre beaker is placed over the arrangement (Figure 6).

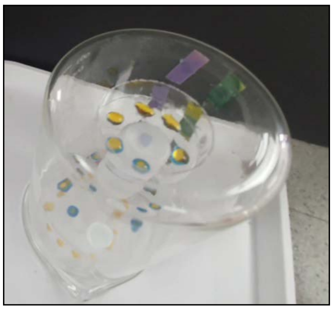

Figure 7: Ammonia diffusing in 3 dimensions to fill an inverted 1 litre beaker

Ammonia is lighter than air and so the gas rises to affect the indicators on the top tier. Diffusion then proceeds so that the indicators on the bottom tier are affected. The gas has now diffused throughout the whole beaker.

Now use the same arrangement but use drops of concentrated hydrochloric acid in the blister pack. Use drops of bromothymol blue indicator in tap water (slightly alkaline) and dampen any indicator strips with tap water.

There is a video available[4].

References

[1]See https://tinyurl.com/4d9b4kre

[2]See the video https://youtu.be/Jun8_OgvAPE

[3]See the video https://www.youtube.com/watch?v=BKrbePYoxc4

[4]See https://www.youtube.com/watch?v=3qCaXVfp-Dg

'Why do I need to know this?'

Toxic and highly flammable gases do not separate into two layers (like vegetable oil and water) in air. There is a layer to begin with but, even without draughts, these gases will diffuse to occupy the whole volume into which they are released.

- Toxic gases denser than air such as hydrogen sulfide and mercaptans found in sewers will poison the workers.
- Toxic gases denser than air such as chlorine used in swimming pools will poison the users.
- Gases less dense than air such as methane (an asphyxiant) and toxic carbon monoxide will kill miners.
- Highly flammable gases less dense than air such as methane and carbon monoxide form air-explosive mixtures.
- Highly flammable gases denser than air such as butane and other LPGs form air-explosive mixtures.

