Alternative Demonstrations of Slow Processes IV: Video Clips Presenting Diffusion in Gases and Liquids

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Abstract: It is well known that long-lasting (marathon) chemical experiments are not convenient for use as classical chemical demonstrations, simply due to their duration. Thus, the phenomena of chemical waves, diffusion, osmosis, etc, although very attractive and with high education value, are not suitable as lecture demonstrations. Some of them are often organized as corridor or exhibition demonstrations. In order to enable instructors to demonstrate these phenomena in real time, we offer the fast-motion technique, condensing an experiment that originally lasts several hours or even days into a half-minute movie. Examples are given for gas–gas and solid–liquid diffusion and are supported by video clips.

Introduction

Marathon experiment or simply marathon is a name used to describe long-lasting experiments (experiments that last much longer than 15 min) [1, 2]. Typical marathon experiments are those involving osmosis [3], diffusion [4, 5], chemical waves [6], paper chromatography [7], spontaneous distillation [8], and many others.

Because the phenomena take a long period of time, they are not suitable as classical demonstrations. Yet, it is possible (as demonstrated on several occasions [9–11]) to accelerate the process, employing the fast-motion technique. The technique is based on taking a series of photographs at regular time intervals (20 s, 5 min etc.) and making a short movie that contains the important information and the details about the slow process.

In the present paper we offer two video clips showing diffusion in gases and in aqueous solution. The demonstrations are only qualitative. An attempt to present quantitative results will be presented in a forthcoming contribution [12]. During the preparation of this material, a paper on diffusion as a laboratory experiment appeared [13].

Transport Phenomena: Diffusion

Let us consider a sample of gas that is not in internal equilibrium [14]. One may define a *transport property* of the sample in question as its ability to transfer matter, energy, linear momentum, etc. from one place to another because of the existence of an appropriate gradient. The phenomena associated with the above properties are known as *transport phenomena*. Examples of the above may be given in terms of *migration of a substance* caused by existence of a concentration gradient (diffusion); *migration of energy* caused by a temperature gradient (thermal conduction); *migration of linear momentum* caused by a molecular velocity gradient (viscosity), etc.

If, therefore, an amount of substance is transferred from one part of our gaseous sample into another, the process is named *diffusion*. Providing all other parameters are the same, the higher the concentration gradient, the faster the rate of the process. During the diffusion process, the concentration gradient decreases and when the concentrations become equal the system reaches equilibrium. Diffusion is therefore a *spontaneous* process.

The rate of diffusion depends on the mass (or the molar mass) of the diffusing particles, the rate increases as the mass decreases. In terms of Graham's law, we can say that *the rate of diffusion in gasses is inversely proportional to the square root of their molar mass (i.e. density)*, that is,

$$\frac{v_A}{v_B} = \sqrt{\frac{M_r(B)}{M_r(A)}}$$

Diffusion is present not only in gases, but also in liquids (and even solids). Of course, in the condensed phases, the process is much slower then in gasses.

Experimental

This demonstration includes two experiments: diffusion of bromine vapor in air and diffusion of potassium permanganate in water. Both illustrate the same process (diffusion) but in different phases (the first one in the gaseous phase and the second one in the liquid).

1. Diffusion in Gases. The diffusion of bromine vapor in air is an appropriate demonstration for this kind of processes. Surely, it is pointless to work with colorless gases because we could not follow the process visually. Bromine is a reddish-brown liquid at room temperature, but its vapor pressure is high enough to ensure fast evaporation when it is put into a vessel. Bromine vapor has an intense red-orange color.

Chemicals and Equipment. Bromine, an aqueous solution of potassium iodide and starch, two glass cylinders, glass tube, graduated pipette, filter paper, digital camera (Philips ToUcam XS was used in our experiment) coupled to a PC. Adobe Premiere software was used for video editing.

The Experiment*.* This experiment demonstrates diffusion in gasses (diffusion of bromine vapor into air). A few drops of bromine are put into a glass cylinder connected with a glass tube to a second cylinder. A filter paper soaked with a solution of KI and starch is put into the

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Figure 1. Diffusion of bromine in air, the equipment used, and the beginning of the experiment.

Figure 2. The diffusion of bromine progresses; the paper soaked with a solution of KI and starch turns blue.

Figure 3. Diffusion of bromine; with excess bromine, the paper is discolored.

Figure 4. Diffusion of bromine, equilibrium is reached.

second cylinder. The equipment used in this experiment is shown in Figure 1.

The reddish-brown vapor moves upward, slowly filling the entire cylinder. The vapor then passes through the glass tube into the second cylinder. Initially, the vapor in this cylinder cannot be seen due to its low concentration. Still its presence could be ascertained by the appearance of the blue color on the filter paper (caused by the displacement reaction of the iodine from potassium iodide by bromine). It is well known that the inclusion compound of iodine with starch exhibits a characteristic and intense blue color (Figure 2).

Iodine is further oxidized to (colorless) iodic acid by the excess of bromine:

$$I_2(aq) + 6H_2O(l) + 5Br_2(g) = 10HBr(g) + 2HIO_3(aq)$$

As a result, the filter paper becomes colorless (Figure 3).

The color intensity in the second cylinder increases with time, so that it is obvious that more bromine vapor is transferred as the diffusion process advances. Actually, the process continues (albeit at a decreasing rate) until the concentrations of the bromine vapors in both cylinders become equal. Providing that identical cylinders are used, the color intensity in both vessels should be uniform at this point. Because we used cylinders with different thickness in this experiment, the color intensity is different (cf. Figure 4).

The experiment lasts more than 60 min, which is much too long a period for class demonstration; therefore we propose another, timesaving way to demonstrate the same phenomenon. As we did several times earlier [9–11] we suggest that the fast-motion technique be used. That is, a series of photographs are taken at 5 s intervals and are connected into a short movie (video clip). As was a common practice so far, music has been added to enhance the clip.

2. Solid–Liquid Diffusion. The diffusion processes can be demonstrated not only in the case of gases, but also in condensed phases. An example could be the spontaneous dissolution of a solid substance in a suitable liquid (usually in water) followed by formation of a colored solution. This is an example of solid–liquid diffusion.

Chemicals and Equipment. Potassium permanganate, distilled water, a large test-tube and a stand, rubber stopper, filter paper, digital camera (Philips ToUcam XS) coupled to a PC. Adobe Premiere software was used for video editing.

The Experiment. There are many solid substances that are soluble in water and that give colored solutions, so the number of possible choices is large. $KMnO_4$ was used in our experiment, although $CuSO_4$•$5H_2O$, $NiSO_4$•$7H_2O$, $KCr(SO_4)_2$•$12H_2O$, $K_2Cr_2O_7$ etc. could also be used. The use of $KMnO_4$ for this purpose has the advantage of giving a very intensely colored solution.

The $KMnO_4$ crystals have a dark red or violet color with metallic luster. As most salts, it dissociates instantaneously in aqueous solution. The MnO_4^- ions are generally considered to be stable in a wide range of pH values. In the presence of organic substances (impurities) they may be reduced to MnO_2.

Very simple equipment can be used to demonstrate this process: a glass cylinder, a test tube, or even a glass pneumatic trough; however, the experiments carried out in a test tube have a certain advantage: the length of the test tube is smaller than that of a cylinder, so that the process is less time-consuming.

Different approaches for performing the experiment are possible. We tried the following: a lump of $KMnO_4$ is set on a coin, wrapped with a filter paper, and put at the bottom of a glass test-tube which is clamped on a stand and corked to prevent water evaporation. This is seen more clearly in Figure 5a.

Almost immediately, a reddish-violet color appears in the solution at the bottom of the test tube, indicating the beginning of the dissolution process. Permanganate ions gradually diffuse upwards as a result of a tendency to equalize the concentration in the whole system (Figure 5b). The color intensity is greater near the bottom and decreases on moving upwards. After a couple of days a brown turbidity is observed at the bottom of the test tube (a consequence of reduction of $KMnO_4$ by the filter paper to MnO_2). The redox reaction (more precisely the half-reaction) of the reduction of Mn(VII) to Mn(IV) in neutral media is represented by the following equation:

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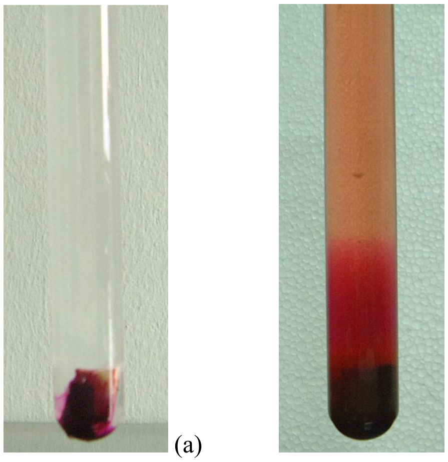

(a) (b)

Figure 5. (a) Diffusion of $KMnO_4$ in water, the beginning of the process. (b) Diffusion of $KMnO_4$ in water; after a few days, the filter paper is oxidized by the permanganate (note the brown precipitate near the test tube's bottom).

$$MnO_4^-(aq) + 2H_2O(l) + 3e^- = MnO_2(s) + 4OH^-(aq)$$

To avoid this undesirable effect, one can simply put a sufficiently large crystal of $KMnO_4$ into the test-tube filled with water. Photographing (in intervals of 5 min.) starts at the moment when the $KMnO_4$ lump is at the bottom. A half-minute movie of the process (that originally lasts for 2 days) was created again using the fast-motion technique.

Safety Tips and Disposal. Liquid bromine is an extremely toxic and irritating substance. It causes severe skin burns. Furthermore, it easily evaporates, producing a heavy poisonous vapor that can cause respiratory problems. The experimenter should always work in a hood and wear suitable gloves and face shield. In case of eye contact, the eyes should be washed with plenty of water (or with a mild solution of sodium hydrogen carbonate) and medical assistance should be sought immediately. Cases have been reported where serious injuries occurred upon skin contact with liquid bromine. To prevent this, in case of contact with the skin, immediately wash with copious amounts of water. After that, a mixture of ammonia and sodium hydrogen carbonate should be applied, and if necessary the skin could be washed again with water and then with a solution of sodium thiosulfate.

A sealed glass tube is the safest way of storing bromine for indefinitely long periods especially if it is kept at low temperatures (in a refrigerator).

Conclusion

Both experiments presented above last too long to be used as demonstrations. The video clips, however, are short enough and still contain practically all the relevant information for the processes, so that they can be safely used as substitutions for the originals. Furthermore, the use of the video clips is a completely safe alternative for less experienced instructors. We are always ready to provide advice to anyone that is interested in repeating (or improving) these demonstrations.

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Supporting Materials. Both video clips are available in a Zip file (http://dx.doi.org/10.1333/s00897061051a).

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