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The Concentration Distance and the Average Kinetic Energy of a Diffusible Solute in its Medium

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Seven sets of diffusible samples were allowed to diffuse in their medium in order to observe how much meters of distance a given volume of sample will cover in its medium at particular condition. At the same time also to observe how much joules of average kinetic energy that given sample volume possess during the course of its traveling. After successful diffusion by using suitable apparatus, all data associated with this study was carefully observed repeatedly and recorded. In which, mean values were used. Series of findings were found including new equation $X_c = \frac{C_n \text{ x } E_k}{D_n \text{ x } F}$ which can be used in determining this new initiative (concentration distance of a diffusible solute in its medium (X_c)).

Keywords: *Concentration distance; average kinetic energy; time of diffusion; diffusible solute; medium.*

1. INTRODUCTION

In chemistry and materials science, diffusion refers to the movement of fluid molecules in porous solids [1]. Scientists already solved many aspects in different types of diffusion in science both theoretically and mathematically. In modern science, the first systematic experimental study of diffusion was performed by Scottish physical chemist Thomas Graham. He studied diffusion in gases, and the main phenomenon was described by him in 1831-1833 [2]. His work provides a basis for separating isotopes by diffusion, a method that came to play a crucial role in the

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development of the atomic bomb [3]. Even Robert Boyle became successful scientist in demonstrating diffusion in solids in the 17th century [4]. By penetration of zinc into a copper coin. Likewise, William Chandler Robert Austen, the well-known british metallurgist and former assistant of Thomas Graham studied systematically solid state diffusion on the example of gold in lead in 1896 [5]. Like physical chemists, also uncountable number of physicists contributed in many ways in solving problems associated with diffusion. The theory of the brownian motion and the atomistic backgrounds of diffusion were developed by Albert Einstein [6]. Though, the particle diffusion equation was originally derived by Adolf Fick in 1855 [7]. Although, Thomas Graham found experimentally that the rate of diffusion of a gas is inversely proportional to the square root of the molar mass of its particles [8]. Diffusion is one of the very important concepts discovered in 19th century and its applications cannot be over emphasized. Diffusion equation is used to figure out the sediment influx and time series of landform changes [9]. However, science is demanding to know the peak distance value that a given diffusible solute of any form can covered in its medium during the course of freely traveling. As a result, this manuscript aimed for telling how far a sample volume of any given diffusible solute will cover in its plentiful supply of medium. At the same time, also to know its average kinetic energy.

2. METHODOLOGY

About eight 4m long and 4cm in diameter white colour pipes ware cut vertically into almost two equal parts each by an export plumber. That is sixteen 4m long and 4cm in diameter white colour vertically open pipes. Eight of these vertically open pipes were joined together to obtained about 32m and 4cm in diameter white colour vertically open pipe. Remaining eight also followed same as first eight. The pipes were then calibrated in meters. The ends of each pipes were joined by using white colour material in a such way that water will not falls down during traveling. Now, one ends of each long white colour open pipe was closed using white material and open cup-like material was used to close other ends. The capacity of this open cup-like material is about 20cm^3 and is a white in colour. Cleaned and dried 32m long vertically open pipe with cup was placed horizontally on the level ground flow. Due to the dissolution effect and experimental time of diffusion delay of some solutes, commonly solids, the experimental concentration distance and experimental time of diffusion can be access by increasing the flow of particles. Here there is need of pressure. To achieve this, the process must consist of both bulk flow and diffusion. Bulk flow in the sense that pressure moves the particles to the certain distance (point where there is difficult in sample colour detection by human eye). That is, high pressure at the pouring point when water volume decreased and low pressure inside the pipe when water volume increases. And diffusion in the sense that after pressure stop, the diffusible particles will continue to their course of diffusion till reached their concentration distance. And this can be explaining bellow. About 3cm^3 of purple potassium tetraoxomanganate (vii) crystals was measured and transferred into pestle and mortar for size reducing. An exactly 1cm^3 of this size reduced crystal was measured by using 1cm^3 capacity material and transferred into 10cm^3 of distilled water at 298k inside beaker. This was then mixed gently till all size reduced crystals dissolved. 1cm^3 of this mixture was added to 9cm^3 of distilled water at 298k and mixed gently. This was then poured into that cup-like material. Now, only 0.1cm^3 of sample was available in 10cm^3 of water. Distilled water at 298k with specific conductivity of 1.5us/cm was used throughout of this work. This water was then continuous supplied gently inside the cup. The cup was filled-up and started follow the long pipe. Water was continuous supplied gently till all visible purple colour of potassium tetraoxomanganate (vii) disappeared from the cup to the end point of traveling inside the pipe (point between inside the cup and pipe where no any purple colour detected by the human eye). The experiment was repeated severally under the same condition for all 0.1cm^3, 0.5cm^3 and 1.0cm^3 volume of sample. Direct replica method goes to orange potassium heptaoxodichromate (vi), blue-green iron (ii) tetraoxosulphate (vi) heptahydrate, blue copper (ii) tetraoxosulphate (vi) pentahydrate and purple-red iron (iii) chloride. Experimental time taken for some samples to completely diffuse was carefully recorded with the aid of electronic stop watch. 0.1cm^3, 0.5cm^3 and 1.0cm^3 of both propan-2-one and formaldehyde were placed separately each at different time inside a 250cm^3 open gas jar capacity, in order to diffuse. Experimental time taken for all amount of volume of samples to

Table 1. Chemical Identification

Name OF Chemicals	Company Name	Cas Number	Purity (%)
Potassium tetraoxomanganate(vii)	CDH	7722-64-7	99.0
Potassium heptaoxodichromate(vi)	ALFA AESAR	7778-50-9	99.5
Iron (ii) tetraoxosulphate (vi) heptahydrate	CDH	7782-63-0	99.0
Copper (ii) tetraoxosulphate (vi) pentahydrate	CDH	7758-99-8	99.0
Formaldehyde	CDH	50-00-0	37-41
Propan-2-one	CDH	67-64-1	99.0

completely diffuse was carefully recorded with the aid of electronic stop watch. After undergoing series and repeated number of observations, mean experimental time of diffusion and concentration distance were recorded for some samples volume. Theoretical time taken for each individual sample to completely diffuse was obtained by using Graham's law of diffusion of gases equation, provided that 70cm^3 of hydrogen gas with relative molecular mass of 2 will diffused at exactly 10 seconds. The density of each sample in kg/m^3 was recorded in tables and their volumes were recorded in m^3. Company name, cas number and percentage purity of some chemicals used are shown in the above table.

3. RESULTS

The purpose of this study is to observe the concentration distance and average kinetic energy of diffusible solute in its medium during the course of its traveling.

4. DISCUSSION

Among the limitations, during traveling of samples, diffusion is associated with dissolution. That is, as diffusion continuous the intensity of colour of sample decreases by achieving dissolution. Therefore, more difficult to detect colour with human eye. For colourless samples, no experimental concentration distance recorded due to difficulty in observation. And for coloured samples, no experimental time of diffusion recorded due to multiple stages used in this work for attempting their time of diffusion.

4.1 Time of Diffusion

The time of diffusion for all samples is the time in which the solute starts diffuse to the time it completely diffused in sufficient amount of medium. It may be experimental time of diffusion (D_{te}) or theoretical time of diffusion (D_{tt}), all measure in second. But the accuracy of this time can only be obtained theoretically due to the dissolution effect of a given solute. As a result, for shortcut, the theoretical time of diffusion can be called time of diffusion (D_t). So, the time of diffusion can be easily found by using Graham's law of diffusion equation. In this case the time taken by the sample to completely diffused is the target not its rate of diffusion. Provided that 70cm^3 of hydrogen gas will diffused in 10 seconds.

4.2 Volume of Sample (v)

0.1cm^3, 0.5cm^3 and 1.0cm^3 of samples were chosen because to minimized difficulties in the experiments. Volume is also choosing instep of mass in order to facilitate concentration distance and average kinetic energy resultants. Since the value of diffusible solute is best handling in volume than in mass for both practical and industrial applications.

4.3 Root Mean-square Velocities of Diffusible Solute Particles in Medium ($\bar{\nabla}$ or $V_{r.m.s}$)

Due to variation of particles movement and constant moving in different directions, the velocity could equal zero. But velocity is a vector quantity, equal to the speed and direction of a particle. To solve the average velocities, $V_{r.m.s}$ are needed which is given by $V_{r.m.s} = \sqrt{\frac{3RT}{Mm}}$

Whereas $V_{r.m.s}$ is root means-square (RMS) velocity (m/s), R is the gas constant with mathematical value of (8.3145), T is absolute temperature in Kelvin and Mm is the molar mass of the solute particles in Kg/mol. This equation is applicable to all diffusible matter whose particles constant movement is in different direction. Since this yield resultant velocity of zero and $V_{r.m.s}$ equation is formulated in order to overcome this problem.

Table 2. for 0.1cm^3 volume of the sample

Compound	v(m^3)	p (kg/m^3)	D_{tt} (Sec.)	D_{te} (Sec.)	V_{rms} (m/s)	X_{ce} (m)	X_{ct} (m)	E_k (Joule)	Colour
$KMnO_4$	$1\ 10^{-7}$	2700	0.126987866		216.8760337	8.780	27.54062477	6.3498	Purple
$K_2Cr_2O_7$	$1\ 10^{-7}$	2676	0.173259566		158.9558684	6.600	27.54062477	3.3807	Orange
$FeH_{14}O_{11}S$	$1\ 10^{-7}$	1898	0.168432144		163.5116908	6.460	27.5406248	2.5373	Blue-green
$CuH_{10}O_9S$	$1\ 10^{-7}$	2270	0.159620083		172.5385938	6.850	27.5406248	3.3789	Blue
$FeCl_3$	$1\ 10^{-7}$	2900	0.128652354		214.0701181	7.100	27.54062476	6.6448	Purple-red
CH_2O	$1\ 10^{-7}$	815.3	0.055352303	0.6200	497.5515552		27.54062444	10.092	Colourless
C_3H_6O	$1\ 10^{-7}$	784.5	0.076983962	0.6800	357.7449603		27.54062443	5.0201	Colourless

Table 3. for 1.0cm^3 volume of the sample

Compound	v(m^3)	p(kg/m$^{3)}$	D_{tt} (Sec.)	D_{te} (Sec.)	V_{rms} (m/s)	X_{ce}(m)	X_{ct}(m)	E_k (Joule)	Colour
$KMnO_4$	$1\ 10^{-6}$	2700	1.269878663		216.8760337	14.220	275.4062476	63.4975	Purple
$K_2Cr_2O_7$	$1\ 10^{-6}$	2676	1.73259566		158.9558684	12.100	275.4062477	33.8072	Orange
$FeH_{14}O_{11}S$	$1\ 10^{-6}$	1898	1.684321449		163.5116908	11.980	275.406248	25.3725	Blue-green
$CuH_{10}O_9S$	$1\ 10^{-6}$	2270	1.596200838		172.5385938	12.200	275.4062481	33.7885	Blue
$FeCl_3$	$1\ 10^{-6}$	2900	1.286523547		214.0701181	13.700	275.4062476	66.4477	Purple-red
CH_2O	$1\ 10^{-6}$	815.3	0.553523036	1.520	497.5515552		275.4062474	100.9168	Colourless
C_3H_6O	$1\ 10^{-6}$	784.5	0.769839629	1.980	357.7449603		275.4062475	50.2007	Colourless

Table 4. for 0.50cm^3 volume of the sample

Compound	v(m^3)	p(kg/m$^{3)}$	D_{tt} (Sec.)	D_{te} (Sec.)	V_{rms} (m/s)	X_{ce}(m)	X_{ct}(m)	E_k (Joule)	Colour
$KMnO_4$	$5\ 10^{-7}$	2700	0.634939331		216.8760337	24.880	137.7031237	31.7488	Purple
$K_2Cr_2O_7$	$5\ 10^{-7}$	2676	0.866297829		158.9558684	20.120	137.7031239	16.9036	Orange
$FeH_{14}O_{11}S$	$5\ 10^{-7}$	1898	0.842160724		163.5116908	19.870	137.703124	12.6863	Blue-green
$CuH_{10}O_9S$	$5\ 10^{-7}$	2270	0.798100419		172.5385938	20.600	137.703124	16.8942	Blue
$FeCl_3$	$5\ 10^{-7}$	2900	0.643261773		214.0701181	21.130	137.7031238	33.2239	Purple-red
CH_2O	$5\ 10^{-7}$	815.3	0.276761518	1.110	497.5515552		137.7031237	50.4584	Colourless
C_3H_6O	$5\ 10^{-7}$	784.5	0.384919814	1.320	357.7449603		137.7031236	25.1004	Colourless

4.4 Concentration Distance

This is the distance covered by a diffusible solute from starting point to the last point of its travelled. The concentration distance may be experimental or theoretical and both measure in meter. Experimental concentration distance (X_{ce}) cannot be obtained accurately due to the dissolution of solute particles during their course of traveling. But theoretical concentration distance (X_{ct}) can always be obtained accurately and is the product of both $V_{r.m.s}$ and D_{tt}. As a result, for shortcut, the theoretical concentration distance can be simply called concentration distance (X_c) that is, $X_c = \sqrt{\frac{3RT}{Mm}} \times D_t$ The concentration distance of equal volume of all diffusible samples is equal at the same temperature, as seen in tables 2, 3 and 4. Like lattice and bond energies, concentration distance and time of diffusion to reach concentration distance for any given sample of diffusible solute cannot be measured experimentally accurate. They can only determine theoretically. Since the manuscript is launching a new initiative (concentration distance of a diffusible solute in its medium and its mathematical equation). The initiative is just to break the barrier and to advancing the science of chemistry and physics for both modern and future used. Due to the broad applications of the initiative, the work found another way of formulating the above equation for better scientific used in all disciplines. And the equation is:

$$X_c = \frac{C_n \times E_k}{D_n \times F}$$

Whereas X_c is concentration distance of diffusible solute in its medium

C_n is number of interactive components
D_n is group number of diffusible solute
E_k is average kinetic energy of diffusible solute

F is applied force exerted by diffusible solute in attempting its average kinetic energy during the course of its traveling.

All the parameters have been defined mathematically including the moving acceleration of diffusible solute.

C_n values of all interactive components used in this work is (2), that is, sample and medium e.g., potassium heptaoxodichromate (vi) and water or sample and medium e.g., formaldehyde (formalin) and air.

D_n values of all group number of diffusible solute used in this work is (1), that is, only one sample diffused in its medium e.g., only potassium tetraoxomanganate (vii) diffused in water at that given time or only propan-2-one diffused in air at that given time.

4.5 Colour of Sample

This is the colour of solute sample seen immediately after it starting diffused in its medium. It is important to know that, the sample may be colourless, and mostly coloured samples were choosing for the target of visibility.

4.6 Average Kinetic Energy of Diffusible Solutes/Particles during their Traveling in their Medium

In addition to external temperature in the medium, diffused particles also exert another temperature to the medium in attempted to exhibit a special property of dissolution (heat of solution). The volume of chemicals in chemical energy will convert to thermal energy in order to provide fuel for kinetic energy. This fuel (thermal energy (temperature)) is measure of average kinetic energy. The volume of these particles in chemical energy converted to thermal energy which will serve as agent for their kinetic energy. Only half of this volume of particles of chemical energy is available in obtaining their possessive kinetic energy. Since other half already converted to thermal energy. Now, we have $^1/_2$v. Where v is volume of sample used, measure in (m^3). Density (p) is the motor driving force for diffusible particles to possess their kinetic energy. This density is measure in (kg/m^3). Since kinetic energy is for moving object, and moving velocity for these diffused particles is V_{rms} measure in (m/s). In order for diffused particles to possess their average kinetic energy, their V_{rms} must be squared in the equation; rather the equation is partial momentum. Whereas average kinetic energy for diffused particles (E_k) is measure in (joule).

E_K = Work done

Average kinetic energy for diffusible particles (E_K) = F x s

$E_K = F \times s$
$F = ma$
$m = vp$
$a = \frac{\sqrt{3RT/Mm}}{t}$

$s = \left(\frac{\sqrt{3RT/Mm}}{2} + 0\right) t \quad = \frac{\sqrt{3RT/Mm}}{2} t$

Since s = average speed x time

Therefore, $E_K = F \text{ x } s$

$E_K = vp \frac{\sqrt{3RT/Mm}}{t} \text{ x } \frac{\sqrt{3RT/Mm}}{2} t$

$E_K = ½vp\sqrt{\frac{3RT}{Mm}}^2$

Partial momentum (M_p) which can be measure in (Newton second (Ns)), is highly minimal here, and this is because, there is very little tendency for that diffused particles to continuous travel in straight line. And is

given by $M_p = {}^{1}/_{2}vp\sqrt{\frac{3RT}{Mm}}$

Since F is force measure in (N), t is time measure in (s), s is distance measure in (m) and a is acceleration measure in (m/s^2). Partial momentum is one of the important quantities that our great scientists remain unreacted to break the barrier to reach. The partial momentum of non-diffusible substance is preferred to write as ($M_P = {}^{1}/_{2}mv$). Where m is mass (kg) and v is velocity (m/s). Partial momentum occurs when almost half of internal energy of that given straight line moving object loses by an external agent, or when half mass of that object disintegrated in forming energy during its movement in straight line. When this happens, the value of momentum will fall down since the velocity of that moving object decreased by half or nearly half e.g., if it is energy lost or the value of mass decreased by half e.g., if it is mass disintegration. The object maintained the ability to continuous traveling in straight line but in partial momentum. Other parameters were already defined above.

5. CONCLUSION

The concentration distance of diffusible solute in its medium is the product of its both root mean square velocity and time of diffusion during its course of traveling. $X_c = \sqrt{\frac{3RT}{Mm}} \text{ x } D_t$

Also can be written as *:* $X_c = \frac{C_n \text{ x } E_k}{D_n \text{ x } F}$

At the same temperature, equal volume of all pure samples of diffusible solutes cover the same value of distance but different possessive average kinetic energy in their medium.

Distance may be of any direction depending on the container shape.

In a very large area of medium, the concentration distance of diffusible solute in its medium is limited.

The average kinetic energy of diffusible particles is $E_K = ½vp\sqrt{\frac{3RT}{Mm}}^2$

The above format of the equation is the best handle for average kinetic energy equation for diffusible solute both in practical and industrial applications. Since volume play more vital role in diffusion than mass.

The possessive average kinetic energy of diffusible solutes is good enough to transform into other forms of energy.

The manuscript also described another important quantity named (partial momentum).

$M_p = {}^{1}/_{2}vp\sqrt{\frac{3RT}{Mm}}$ or $M_P = {}^{1}/_{2}mv$

Some of the applications of this work can be seen in thermodynamics, useful in significant minimizing of global warming, very important in all energy studies, advantageous in increasing or decreasing radioactivity properties of bombardment.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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