The influence of particle size to diffusivity of nanogold particles based on Brownian motion

Zulfahmi¹, Djati Handoko¹*, Prawito Prajitno¹, and Isnaeni²

¹ Department of Physics, Faculty of Science and Mathematics, Universitas Indonesia, Kampus UI Depok, Depok 16424, Indonesia
² Research Center for Physics, Indonesian Institute of Sciences, Serpong, South Tangerang City 15314, Indonesia

* djati.handoko@ui.ac.id

Abstract. Diffusivity calculation has been conducted by many researchers in various methods. One ingenious and sample-efficient way to determine the diffusivity is the examination under the microscope by using microbead random movements, called Brownian motion, through the footage of its movements. This study was conducted to observe the diffusivity of nanogold particles towards the use of various microbead sizes. The one-micron-sized microbead was mixed into nanogold particles solution and prepared onto slide glass, so was the three micron-sized and five-micron-sized microbead. The footage of microbead movements for each size is then tracked and processed using MATLAB image processing to obtain the mean square displacement (MSD) of the microbead and then fitting it to time to find the sample diffusivity. As a result, the nanogold diffusivity observed using one-micron, three-micron, and five-micron-sized microbead is respectively around $5.66 \times 10^{-17}$ cm$^2$s$^{-1}$, $3.45 \times 10^{-17}$ cm$^2$s$^{-1}$, and $1.71 \times 10^{-17}$ cm$^2$s$^{-1}$. Thus, the nanogold diffusivity observed using one-micron-sized microbead is greater than three-micron and five-micron-sized microbead, which can be concluded that the bigger of microbead size used, the smaller diffusivity obtained.

1. Introduction

Diffusivity has been observed by many researchers in various methods. Diffusivity itself is a constant that prescribes the molecular diffusion for a given pair of specimens. As in the study F. A. Bassi et al., they proposed a method to measure the diffusion coefficient based on the refractive index gradient profile by using cylinder lens laser source [5]. One ingenious and sample-efficient way to determine the diffusivity is by examining the microbead particle’s random movements on the observed solution through microscope.

This method uses Brownian motion effect to determine diffusivity. Brownian motion is a phenomenon of the random movement of some particles that can be observed under the objective lens of a microscope caused by the collisions between particles and the molecules of the surrounding liquid [6]. Since the particle moves randomly through the microscope, digital camera is then used to capture the microbead particle movement, which means we use two-dimensional single-particle tracking to find the mean square displacement of the microbead that mixed into a solution by using MATLAB image processing. From the mean square displacement obtained, we are able to determine the diffusivity of the specimen from fitting coefficient of the linear regression with the respect to time interval, correspond to classical Stokes-Einstein behavior in simple fluids [7].
Using this method to measure diffusivity is very efficient for the observed specimen because this method only utilizes the sample quantity at minimum level. S. H. Lee et al. [3] have used this method in observing Fe₂O₃ magnetic cube chains under external magnetic fields, where the diffusivity was modified with the angular dependency on the magnetic field direction.

The specimen that we used in this study is nanogold particle with distilled water solvent. The aim of this study is to observe factors that might affect the nanogold diffusivity towards the use of various microbead sizes. For the microbead sizes, the author uses one-micron, three-micron, and five-micron-sized microbead particle to see how diffusion between nanogold particle and microbead will occur, resulting the diffusivity value.

2. Method

To get the movement footage of the microbead, we need to build an optical system using microscope and digital camera, where the objective lens magnification is 60×. After the microscope and digital camera set, the solution that mixed with the microbead is then prepared onto a special slide glass with around 20 µm deep cutouts in order to create vacuum space for the solution droplet while it covered with cover glass. For the video record setting itself, it uses frame size 3072×2048 pixels, frame rate 1 fps, and duration 60 seconds.

Before the measurement started, the nanogold particle is needed to be divided into 3 different clear bottles. This procedure is intended to mix one droplet (approx. 10 µl) of microbead particles for each size (1, 3, and 5 microns) using 50 µl pipette, which will become the observed sample. After that, the sample is placed onto slide glass then the sample stage is set until getting the focus of the moved microbead. To record the footage of the microbead movements, one thing that should pay attention is that the microbead should move randomly (in every direction), not only in just one direction, which indicates that there is still flow in it that might interfere the diffusivity value.

From the acquired microbead footage, the author uses MATLAB image processing that able to track the microbead trajectory for each frame. There are several steps that need to follow before fitting the trajectory. Firstly, we need to calibrate the scale of the image from the pixel unit to metric. The exact diameter of the particle is measured using the image tool from MATLAB function for each microbead sizes variation. After averaging and dividing the value, we get the estimated length of one pixel of the image. Next, before executing the trajectory tracking process, we need to filter the image from RGB to BW and crop the frame size of the image as small as possible corresponding with the initial and final trajectory of the microbead movements. This step will help accelerate the image tracking process frame by frame.

![Figure 1.](image-url)

(a) Acquired image from the digital camera through microscope. (b) The cropped image (674×563 pixel) corresponding with initial and final trajectory of the microbead movements. (c) The template image (158×158 pixel) for image processing of particle tracking.
To track the microbead trajectory frame by frame, we need to sample the microbead image to become the template image of the process. By using the correlation function in MATLAB [2], the template image will estimate the closest coordinate and pattern that matches the next frame until reaching the end frame of the video sequence. Therefore, we get the coordinate of the microbead and its displacements in time sequence which can be seen in Figure 2.

After getting the displacement data, the specimen diffusivity is then obtained through the mean square displacement (MSD) data by fitting the linear regression, which its coefficient corresponds to Stokes-Einstein equation [6]. MSD is the mean of the squares of all the shifts in xy direction, which is given by Eq. (1) and Eq. (2)

\[ \bar{r}^2(\Delta t) = \frac{1}{M} \sum_{i=1}^{M} (r_i-r_{i+1})^2 \]  

\[ \bar{r}^2(\Delta t) = 2D\Delta t \]  

where \( M \) is the number of measurements along time intervals (\( \Delta t \)), \( r \) is the displacement in xy direction, and \( D \) is the diffusion coefficient.

3. Result and Discussion
From the image processing result conducted above, we find the nanogold diffusivity for one-micron, three-micron, and five-micron-sized microbead respectively around \( 5.66 \times 10^{-17} \text{ cm}^2\text{s}^{-1} \), \( 3.45 \times 10^{-17} \text{ cm}^2\text{s}^{-1} \), and \( 1.71 \times 10^{-17} \text{ cm}^2\text{s}^{-1} \).

We can observe the particle size influence on the nanogold particle diffusivity through the slope in Figure 6. It can be seen from the figure that the higher the slope coefficient of the corresponding size, the more distant displacement of a microbead will occur, which indicates the higher the diffusivity of a specimen would be.
Figure 3. One-micron-sized microbead particle tracking and fitting data

Figure 4. Three-micron-sized microbead particle tracking and fitting data
Figure 5. Five-micron-sized microbead particle tracking and fitting data

Figure 6. Diffusivity of The Nanogold Particle for each microbead sizes variation

4. Conclusion
As a result, this method can be concluded that the influence of the nanogold diffusivity for each microbead size can be defined through their properties, where diffusivity measurement using one-micron-sized microbead is greater than three-micron and five-micron-sized microbead. It indicates that the bigger of microbead size used, the smaller diffusivity obtained.

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