

Surface Area and Volume: Determinants of Diffusion in Specified Organisms

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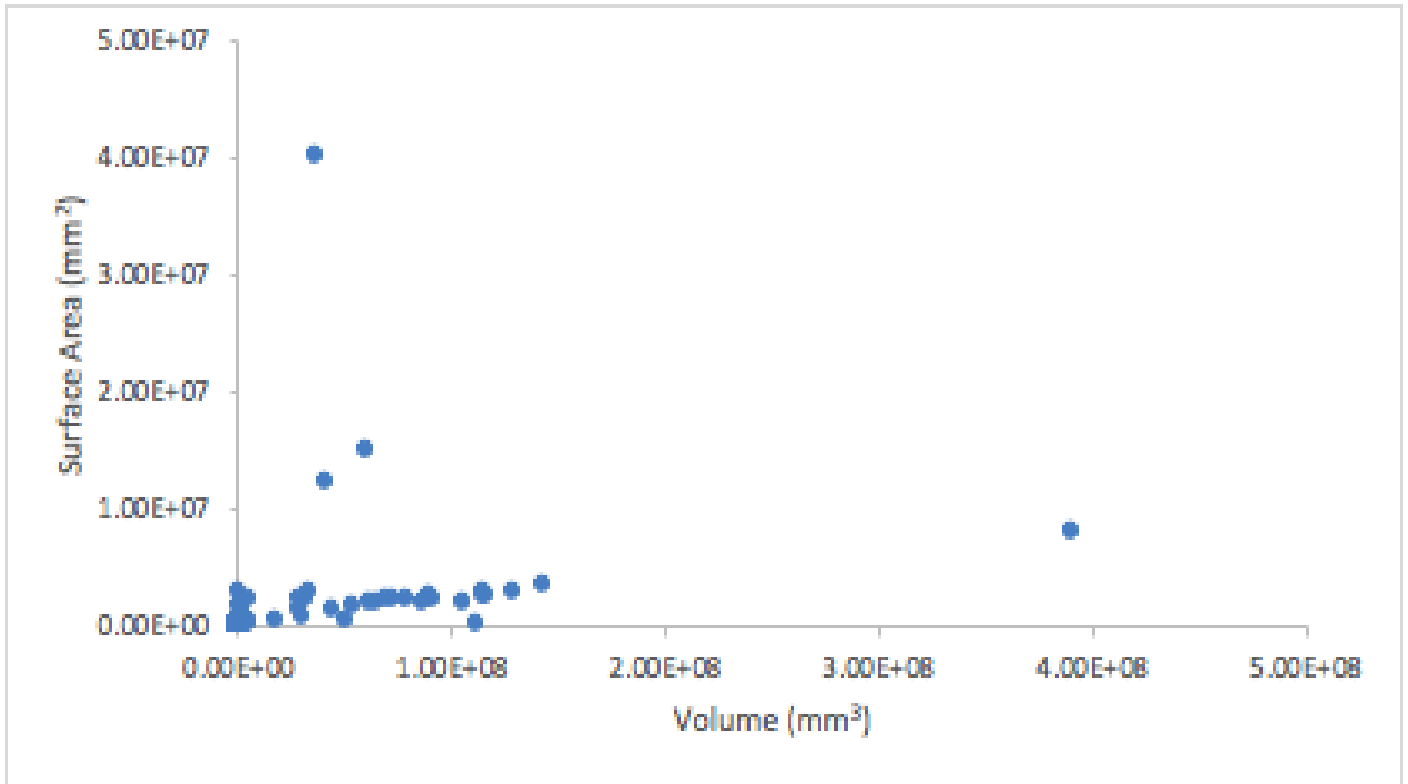


Figure 1: The volume (mm³) plotted against the surface area (mm²) of nine organisms. Included are *Tetrahymena* sp., *Spirostomum* sp., *Planaria* sp., *Fasciola hepatica*, earthworm, sea urchin, perch, turtle, and human. The sample size (n) is 365.

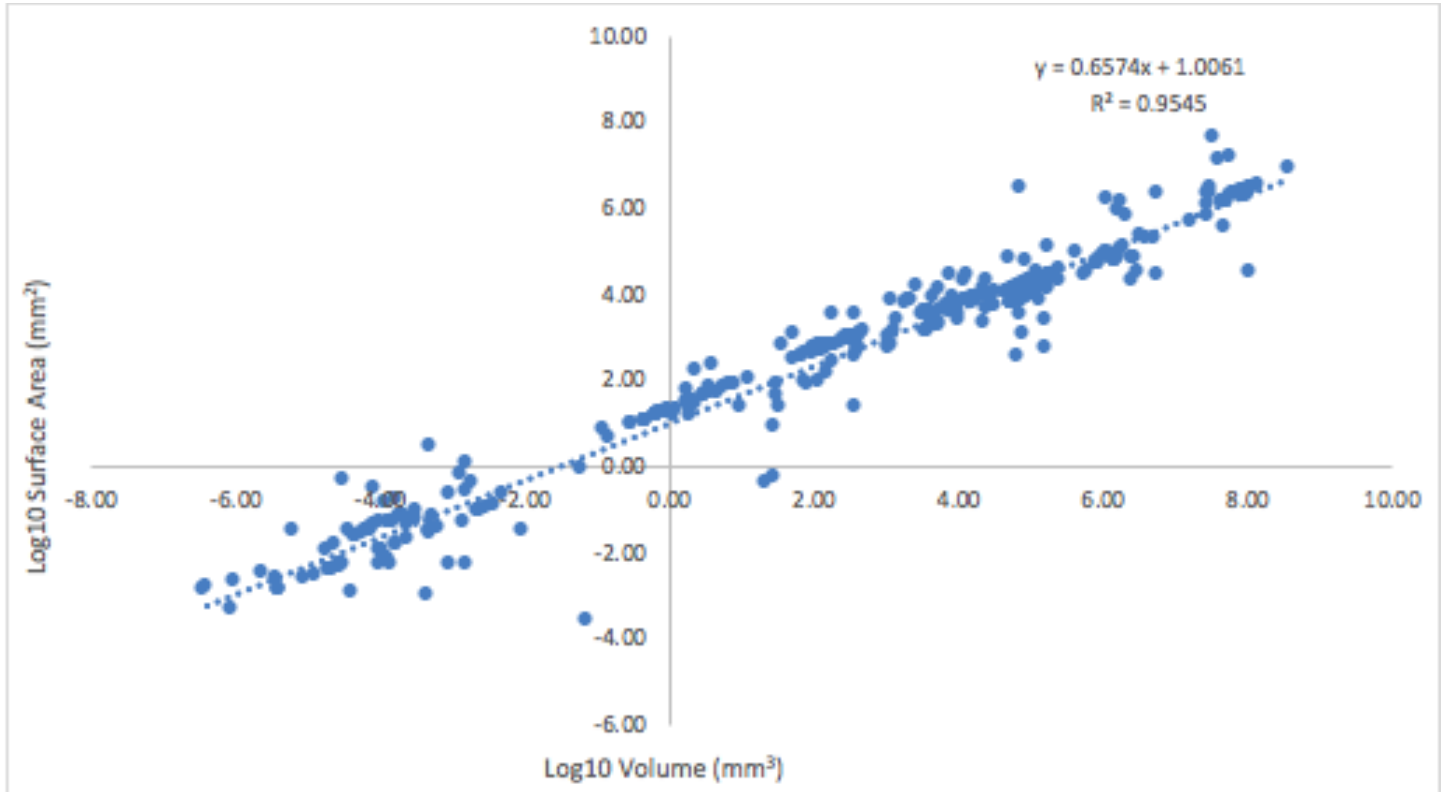


Figure 2: Log10 of organism volume (mm^3) plotted against Log10 of organism surface area (mm^2) of nine organisms. Included are *Tetrahymena* sp., *Spirostomum* sp., *Planaria* sp., *Fasciola hepatica*, earthworm, sea urchin, perch, turtle, and human. The sample size (n) is 365. The slope ($m=0.66$) of this relationship shows a positive correlation ($R^2=0.96$) between Log10 of organism volume and Log10 of organism surface area. The calculated r value ($r=0.98$), with degrees of freedom (DF) of 363 and at a significance level (α) of 0.05, is greater than the critical r value ($r_{\text{critical}} = 0.11$); therefore, the positive correlation is statistically significant.

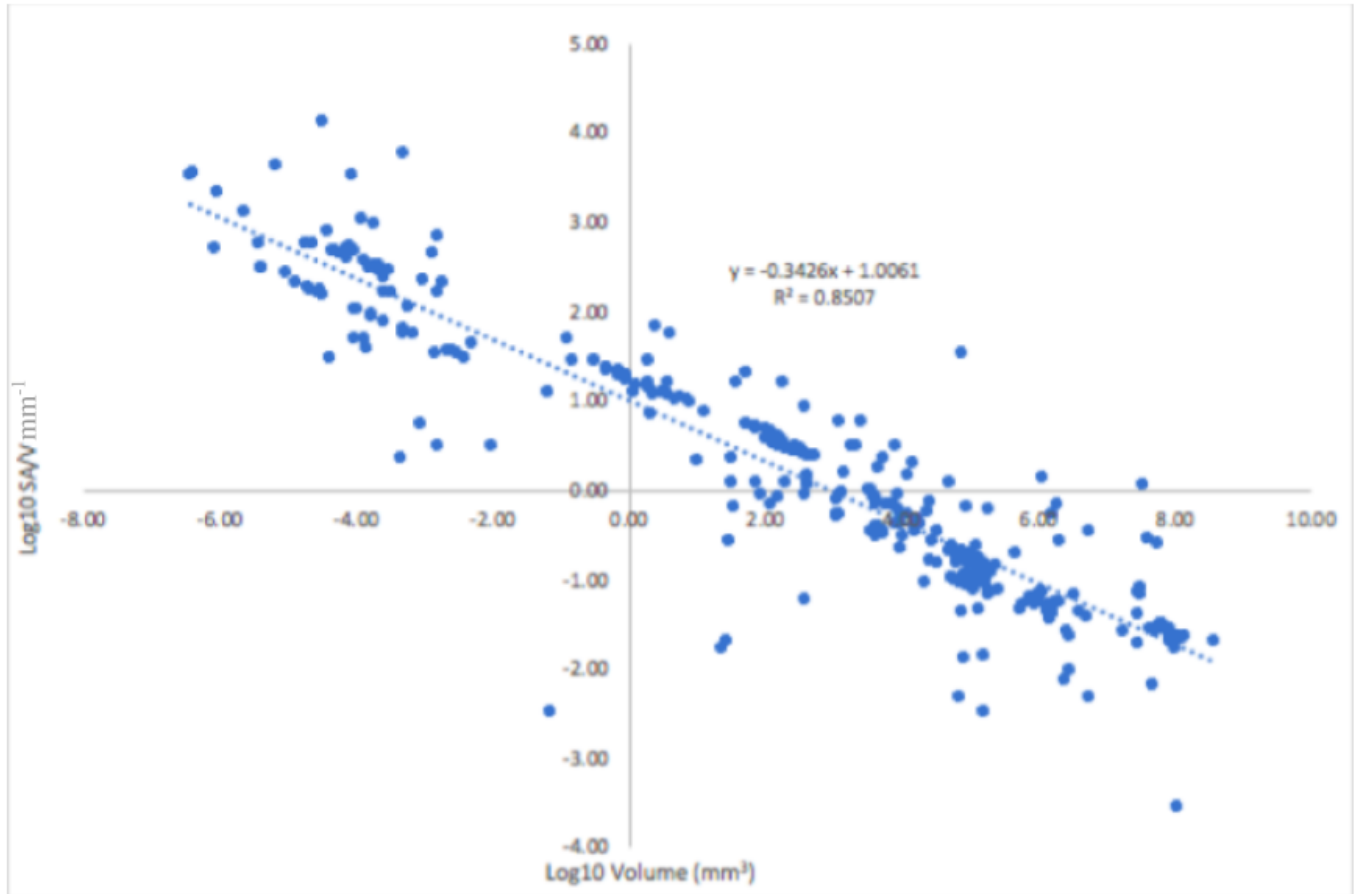


Figure 3: Log10 of organism volume (mm^3) plotted against Log10 of organism surface area to volume ratio (mm^{-1}) of nine organisms. Included are *Tetrahymena* sp., *Spirostomum* sp., *Planaria* sp., *Fasciola hepatica*, earthworm, sea urchin, perch, turtle, and human. The sample size (n) is 365. The slope ($m = -0.34$) of this relationship shows a negative correlation ($R^2 = 0.85$) between Log10 of organism volume and Log10 of organism surface area to volume ratio. The calculated r value ($r = 0.92$), with degrees of freedom (DF) of 363 and at a level of significance (α) of 0.05, is greater than the critical r value ($r_{\text{critical}} = 0.11$); therefore, the negative correlation is statistically significant.

1. What is the problem with the graph from Figure 1?

The graph from Figure 1 does not show a distinct linear regression between the data. The data in the graph is skewed, and there are a number of outliers that may affect the model's performance in statistical analysis. Specifically, concrete information about the two variables (organism volume and organism surface area) and their relationship with each other cannot be derived and/or analyzed from Figure 1.

2. How does the logarithmic transformation in Figure 2 help to fix the problem that is observed in Figure 1 and affect the relationship between surface area and volume?

Log transformation was used in Figure 2 to make the distribution from Figure 1 less skewed. After applying log transformation, Figure 2 clearly shows a linear regression that is easily able to undergo statistical analysis. Therefore, information about the relationship between the surface area and volume of the organisms used in the study can be derived.

Specifically, Figure 2 shows a statistically significant, positive correlation between the surface area and volume of the multiple organisms used in the study. The variables move in tandem—as the volume of an organism increases, the surface area increases as well.

3. (A) Do small animals have a higher or lower surface area to volume ratio compared to larger animals? (B) What might explain this ratio? Two explanations are required: one for small animals and one for large animals.

Figure 3 shows a statistically significant, negative correlation between Log10 of surface area to volume ratio (SA/V) and Log10 of volume of the multiple organisms used in the study. In

other words, as volume increases, the SA/V decreases; conclusively, animals with small volumes have a higher SA/V compared to animals with large volumes. The SA/V can be explained by the fact that an organism's volume increases faster than their surface area. This means that a small animal may have a smaller surface area and a smaller volume than a large animal; however, the difference between the large animal's surface area and its volume is comparatively much larger than the difference between a small animal's surface area and its volume.

4. **(A) How does a change in body shape affect diffusion (Hint: think sphere vs. cylinder vs. rectangle)? (B) Do earthworms have a higher surface area to volume ratio than flatworms?**

A change in body shape affects diffusion by altering the SA/V of the organism. As the SA/V increases, diffusion becomes better facilitated. This is because there is a greater surface for diffusion to take place, with less volume to disperse the diffused particles to. Therefore, an organism with a body shape that gives them a higher SA/V can utilize diffusion more effectively. In the case of the flatworm and the earthworm, earthworms have a lower SA/V than flatworms; therefore, diffusion is more efficient in flatworms.

5. **(A) Which animal (mouse or elephant) has higher energy requirements per unit of mass? (B) How does this affect the animal's metabolic rate?**

A mouse has higher energy requirements per unit of mass. This is because a small organism, such as a mouse, has more body surface relative to its volume of metabolizing tissue; a mouse has a higher SA/V. It is important to note that animals exchange heat with their environments through their body surfaces. Therefore, smaller animals lose heat to cool

environments faster than large animals because small animals have a larger amount of body surface (relative to their volume) to lose heat through. Due to this, small animals require higher amounts of energy to maintain a constant internal temperature and avoid becoming too cold. This in turn requires a higher metabolic rate to generate the additional heat energy that small animals require (OpenStax, 2012).

6. What morphological, behavioural, and/or physiological adaptations do larger animals (including humans) use to be energy efficient while maintaining their body temperature? Please explain for four adaptations.

Larger animals use various adaptations to maintain body temperature efficiently. One important method for generating heat involves muscle contractions. In cold temperatures, random contractions of skeletal muscles (shivering) increase aerobic respiration which produces heat that is used to increase body temperature (OpenStax, 2013).

Another example of thermoregulation utilized by animals involves the circulatory system. It is important to note that the body's surface is the main route of heat loss or gain, therefore circulatory mechanisms can be used to increase body temperature as well as decrease body temperature. To increase body temperature, the superficial arteries at the body's surface are constricted to decrease the flow of warm blood coming from the body's core. This is to reduce heat loss from this blood to the environment, therefore retaining heat in an attempt to increase the body's temperature, or at the very least, impede it from decreasing further. The opposite mechanism is used to decrease body temperature: superficial arteries at the body's surface are dilated. This causes warm blood from the body's core to flow to the body's surface, increasing heat loss to the environment in order to cool the body (OpenStax, 2013).

Evaporation mechanisms are also commonly used in order to decrease body temperature. This can be done via the body surface by sweating, or the surface of the mouth and nose through panting. In both cases, evaporation of moisture on these surfaces takes place. This evaporation dissipates heat from these surfaces, decreasing the animal's body temperature (Koop & Tadi, 2019).

Lastly, many animals utilize some sort of insulation in order to maintain body temperature in cold environments. The goal of an insulative layer is to trap a layer of air next to the body surface in order to reduce heat transfer to the environment. For example, birds may fluff up their wings in order to create an insulative layer, while furbearers do so with their fur. While humans have a response to cold that mimics that of furbearers, it is not as effective due to the sparsity of hair on the human body. Instead, humans take a behavioural approach and use layering of different materials to keep warm and create the insulative layer, including blankets and clothing (Rohrig, 2013).

7. **(A) Would an animal's geographic location (ex. In the hot tropics vs. the cold arctic) affect their surface area to volume ratio? (B) Why might this be? Two explanations are required for the differences between cold and warm climates. (Hint: think about gaining and losing heat).**

An animal's geographic location affects their SA/V. To be more specific, the *climate* of the animal's geographic location affects their SA/V. The rate at which an organism loses heat is partly dependent upon the body surface of the organism. A larger surface area facilitates heat loss to the environment as there is more area for heat exchange to take place. A smaller surface area, on the other hand, does not facilitate heat loss to the same extent, as the area for heat

exchange to take place is smaller. In other words, a larger SA/V would lose heat more rapidly than a smaller SA/V (OpenStax, 2012). With this taken into consideration, it can be understood why the climate of an animal's geographic location can affect its SA/V. Animals living in cold climates benefit from mechanisms that help them stay warm in a cold environment to maintain proper internal temperature. Therefore, a small surface area is beneficial as the rate of heat loss is lower. Thus, animals in a cold climate benefit from a small SA/V. Animals that live in hot climates, however, benefit from mechanisms that keep them cool in a warm environment. Consequently, a large surface area is beneficial in a warm climate as the rate of heat loss is higher. This allows these animals to dissipate heat faster in order to maintain proper internal temperature and avoid overheating.

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