Large surface to volume ratio

Surface area to volume ratio is vital in so many biological processes. When we're talking about cells, which is most of the time, the important point is that the surface area to the volume ratio gets smaller as the cell gets larger. Therefore cells are limited in their size because if the cell grows beyond a certain limit, not enough material will be able to cross the membrane fast enough to accommodate the increased cellular volume. Here are some examples to help to remember how surface area to volume ratio plays its role: If you were living in Africa you would rather have a large surface area to volume ratio as this would help you lose heat faster. Alternatively, if you were living in the Antarctic you would want a small surface area to volume ratio. This would reduce heat loss and conserve it in the body. Obviously it is cold at the Antarctic, so you would want to minimise heat loss. Smaller animals tend to have larger surface area to volume ratios. For instance, a hamster has a larger surface area relative to its volume than an elephant! Elephants have adapted to losing heat faster by having very large ears. This increases their surface area to volume ratio. Heat is released from our bodies during respiration. This helps keep our organs warm, but it can be a problem if you cannot control your body temperature well. In our bodies waste is carried by the circulatory system. The blood carries waste from cells around the body to the lungs, the skin, the liver and to the kidney. But in single celled organisms they get rid of waste by it diffusing across their membranes. As they have a large surface area to volume ratio, diffusion of waste substances occurs rapidly. Surface area per unit volume of an object or collection of objects Graphs of surface area, A against volume, V of the Platonic solids and a sphere, showing that the surface area decreases for rounder shapes, and the surface-area-to-volume ratio decreases with increasing volume. Their intercepts with the dashed lines show that when the volume increases 8 (2^3) times, the surface area increases 4 (2^2) times. The surface-area-to-volume ratio, also called the surface-to-volume ratio and variously denoted sa/vol or SA:V, is the amount of surface area per unit volume of an object or collection of objects. SA:V is an important concept in science and engineering. It is used to explain the relation between structure and function in processes occurring through the surface AND the volume. Good examples for such processes are processes governed by the heat equation,[1] i.e., diffusion and heat transfer by conduction.[2] SA:V is used to explain the diffusion of small molecules, like Oxygen and Carbon dioxide between air, blood and cells,[3] Water loss by animals,[4] bacterial morphogenesis,[5] organism's Thermoregulation,[6] design of artificial bone tissue,[7] artificial lungs [8] and many more biological and biotechnological structures. For more examples see Glazier.[9] The relation between SA:V and diffusion or heat conduction rate is explained from flux and surface perspective, focusing on the surface of a body as the place where diffusion, or heat conduction, takes place, i.e., the larger the SA:V there is more surface area per unit volume through which material can diffuse, therefore, the diffusion or heat conduction, will be faster. Similar explanation appears in the literature: "Small size implies a large ratio of surface area to volume, thereby helping to maximize the uptake of nutrients across the plasma membrane",[10] and elsewhere.[9][11][12] For a given volume, the object with the smallest surface area (and therefore with the smallest SA:V) is a ball, a consequence of the isoperimetric inequality in 3 dimensions. By contrast, objects with acute-angled spikes will have very large surface area for a given volume. SA:V for balls and N-balls A ball is a three-dimensional object, being the filled-in version of a sphere ("sphere" properly refers only to the surface and a sphere thus has no volume). Balls exist in any dimension and are generically called n-balls, where n is the number of dimensions. Plot of the surface-area:volume ratio (SA:V) for a 3-dimensional ball, showing the ratio decline inversely as the radius of the ball increases. For an ordinary three-dimensional ball, the SA:V can be calculated using the standard equations for the surface and volume, which are, respectively, 4 π r 2 {\displaystyle 4\pi {r^{2}}} and (4 / 3) π r 3 {\displaystyle (4/3)\pi {r^{3}}} . For the unit case in which r = 1 the SA:V is thus 3. The SA:V has an inverse relationship with the radius - if the radius is doubled the SA:V halves (see figure). The same reasoning can be generalized to n-balls using the general equations for volume and surface area, which are: volume = r n π n / 2 Γ (1 + n / 2) {\displaystyle r^{n}\pi ^{n/2} \over \Gamma (1+n/2)} ; surface area = n r n − 1 π n / 2 Γ (1 + n / 2) {\displaystyle nr^{n-1}\pi ^{n/2} \over \Gamma (1+{n/2})} Plot of surface-area:volume ratio (SA:V) for n-balls as a function of the number of dimensions and of radius size. Note the linear scaling as a function of dimensionality and the inverse scaling as a function of radius. So the ratio reduces to n r − 1 {\displaystyle nr^{-1}} . Thus, the same linear relationship between area and volume holds for any number of dimensions (see figure): doubling the radius always halves the ratio. Dimension The surface-area-to-volume ratio has physical dimension L−1 (inverse length) and is therefore expressed in units of inverse distance. As an example, a cube with sides of length 1 cm will have a surface area of 6 cm2 and a volume of 1 cm3. The surface to volume ratio for this cube is thus SA:V = 6   cm 2 1   cm 3 = 6   cm − 1 {\displaystyle {\mbox{SA:V}}={\frac {6~{\mbox{cm}}^{2}}{1~{\mbox{cm}}^{3}}}=6~{\mbox{cm}}^{-1}} . For a given shape, SA:V is inversely proportional to size. A cube 2 cm on a side has a ratio of 3 cm−1, half that of a cube 1 cm on a side. Conversely, preserving SA:V as size increases requires changing to a less compact shape. Physical chemistry This section does not cite any sources. Please help improve this section by adding citations to reliable sources. Unsourced material may be challenged and removed. (February 2014) (Learn how and when to remove this template message) See also: Dust explosion Materials with high surface area to volume ratio (e.g. very small diameter, very porous, or otherwise not compact) react at much faster rates than monolithic materials, because more surface is available to react. An example is grain dust: while grain is not typically flammable, grain dust is explosive. Finely ground salt dissolves much more quickly than coarse salt. A high surface area to volume ratio provides a strong "driving force" to speed up thermodynamic processes that minimize free energy. Biology Cells lining the small intestine increase the surface area over which they can absorb nutrients with a carpet of tuftlike microvilli. The ratio between the surface area and volume of cells and organisms has an enormous impact on their biology, including their physiology and behavior. For example, many aquatic microorganisms have increased surface area to increase their drag in the water. This reduces their rate of sink and allows them to remain near the surface with less energy expenditure.[citation needed] An increased surface area to volume ratio also means increased exposure to the environment. The finely-branched appendages of filter feeders such as krill provide a large surface area to sift the water for food.[13] Individual organs like the lung have numerous internal branchings that increase the surface area; in the case of the lung, the large surface supports gas exchange, bringing oxygen into the blood and releasing carbon dioxide from the blood.[14][15] Similarly, the small intestine has a finely wrinkled internal surface, allowing the body to absorb nutrients efficiently.[16] Cells can achieve a high surface area to volume ratio with an elaborately convoluted surface, like the microvilli lining the small intestine.[17] Increased surface area can also lead to biological problems. More contact with the environment through the surface of a cell or an organ (relative to its volume) increases loss of water and dissolved substances. High surface area to volume ratios also present problems of temperature control in unfavorable environments.[citation needed] The surface to volume ratios of organisms of different sizes also leads to some biological rules such as Allen's rule, Bergmann's rule[18][19][20] and gigantothermy.[21] Fire spread In the context of wildfires, the ratio of the surface area of a solid fuel to its volume is an important measurement. Fire spread behavior is frequently correlated to the surface-area-to-volume ratio of the fuel (e.g. leaves and branches). The higher its value, the faster a particle responds to changes in environmental conditions, such as temperature or moisture. Higher values are also correlated to shorter fuel ignition times, and hence faster fire spread rates. Planetary cooling A body of icy or rocky material in outer space may, if it can build and retain sufficient heat, develop a differentiated interior and alter its surface through volcanic or tectonic activity. The length of time through which a planetary body can maintain surface-altering activity depends on how well it retains heat, and this is governed by its surface area-to-volume ratio. For Vesta (r=263 km), the ratio is so high that astronomers were surprised to find that it did differentiate and have brief volcanic activity. The moon, Mercury and Mars have radii in the low thousands of kilometers; all three retained heat well enough to be thoroughly differentiated although after a billion years or so they became too cool to show anything more than very localized and infrequent volcanic activity. As of April 2019, however, NASA has announced the detection of a "marsquake" measured on April 6, 2019 by NASA's InSight lander.[22] Venus and Earth (r>6,000 km) have sufficiently low surface area-to-volume ratios (roughly half that of Mars and much lower than all other known rocky bodies) so that their heat loss is minimal.[23] Mathematical examples Shape CharacteristicLength a {\displaystyle a} Surface Area Volume SA/V ratio SA/V ratio forunit volume Tetrahedron edge 3 a 2 {\displaystyle {\sqrt {3}}a^{2}} 2 a 3 12 {\displaystyle {\frac {{\sqrt {2}}a^{3}}{12}}} 6 6 a ≈ 14.697 a {\displaystyle {\frac {6{\sqrt {6}}}{a}}\approx {\frac {14.697}{a}}} 7.21 Cube side 6 a 2 {\displaystyle 6a^{2}} a 3 {\displaystyle a^{3}} 6 a {\displaystyle {\frac {6}{a}}} 6 Octahedron side 2 3 a 2 {\displaystyle 2{\sqrt {3}}a^{2}} 1 3 2 a 3 {\displaystyle {\frac {1}{3}}{\sqrt {2}}a^{3}} 3 6 a ≈ 7.348 a {\displaystyle {\frac {3{\sqrt {6}}}{a}}\approx {\frac {7.348}{a}}} 5.72 Dodecahedron side 3 25 + 10 5 a 2 {\displaystyle 3{\sqrt {25+10{\sqrt {5}}}}a^{2}} 1 4 (15 + 7 5) a 3 {\displaystyle {\frac {1}{4}}(15+7{\sqrt {5}})a^{3}} 12 25 + 10 5 (15 + 7 5) a ≈ 2.694 a {\displaystyle {\frac {12{\sqrt {25+10{\sqrt {5}}}}}{(15+7{\sqrt {5}})a}}\approx {\frac {2.694}{a}}} 5.31 Capsule radius (R) 4 π a 2 + 2 π a · 2 a = 8 π a 2 {\displaystyle 4\pi a^{2}+2\pi a\cdot 2a=8\pi a^{2}} 4 π a 3 3 + π a 2 · 2 a = 10 π a 3 3 {\displaystyle {\frac {4\pi a^{3}}{3}}+\pi a^{2}\cdot 2a={\frac {10\pi a^{3}}{3}}} 12 5 a {\displaystyle {\frac {12}{5a}}} 5.251 Icosahedron side 5 3 a 2 {\displaystyle 5{\sqrt {3}}a^{2}} 5 12 (3 + 5) a 3 {\displaystyle {\frac {5}{12}}(3+{\sqrt {5}})a^{3}} 12 3 (3 + 5) a ≈ 3.970 a {\displaystyle {\frac {12{\sqrt {3}}}{(3+{\sqrt {5}})a}}\approx {\frac {3.970}{a}}} 5.148 Sphere radius 4 π a 2 {\displaystyle 4\pi a^{2}} 4 π a 3 3 {\displaystyle {\frac {4\pi a^{3}}{3}}} 3 a {\displaystyle {\frac {3}{a}}} 4.83598 Examples of cubes of different sizes Side ofcube Side2 Area of asingle face 6 × side2 Area ofentire cube(6 faces) Side3 Volume Ratio ofsurface areato volume 2 2x2 4 6x2x2 24 2x2x2 8 3:1 4 4x4 16 6x4x4 96 4x4x4 64 3:2 6 6x6 36 6x6x6 216 6x6x6 216 3:3 8 8x8 64 6x8x8 384 8x8x8 512 3:4 12 12x12 144 6x12x12 864 12x12x12 1728 3:6 20 20x20 400 6x20x20 2400 20x20x20 8000 3:10 50 50x50 2500 6x50x50 15000 50x50x50 125000 3:25 1000 1000x1000 1000000 6x1000x1000 6000000 1000x1000x1000 1000000000 3:500 See also Compactness measure of a shape Dust explosion Square–cube law Specific surface area References Schmidt-Nielsen, Knut (1984). Scaling: Why is Animal Size so Important?. New York, NY: Cambridge University Press. ISBN 978-0-521-26657-4. OCLC 10697247. Vogel, Steven (1988). Life's Devices: The Physical World of Animals and Plants. Princeton, NJ: Princeton University Press. ISBN 978-0-691-08504-3. OCLC 18070616. Specific ^ Planinšič, Gorazd; Vollmer, Michael (February 20, 2008). "The surface-to-volume ratio in thermal physics: from cheese cube physics to animal metabolism". European Journal of Physics. 29 (2): 369–384. Bibcode:2008EJPh...29..369P. doi:10.1088/0143-0807/29/2/017. Retrieved 9 July 2021. ^ Planinšič, Gorazd (2008). "The surface-to-volume ratio in thermal physics: from cheese cube physics to animal metabolism". European Journal of Physics European Physical Society, Find Out More. 29 (2): 369–384. Bibcode:2008EJPh...29..369P. doi:10.1088/0143-0807/29/2/017. ^ Williams, Peter; Warwick, Roger; Dyson, Mary; Bannister, Lawrence H. (2005). Gray's Anatomy (39 ed.). Churchill Livingstone. pp. 1278–1282. ^ Jeremy M., Howard; Hannah-Beth, Griffis; Westendorf, Rachel; Williams, Jason B. (2019). "The influence of size and abiotic factors on cutaneous water loss". Advances in Physiology Education. 44 (3): 387–393. doi:10.1152/advan.00152.2019. PMID 32628526. ^ Harris, Leigh K.; Theriot, Julie A. (2018). "Surface Area to Volume Ratio: A Natural Variable for Bacterial Morphogenesis". Trends in Microbiology. 26 (10): 815–832. doi:10.1016/j.tim.2018.04.008. PMC 6150810. PMID 29843923. ^ Louw, Gideon N. (1993). Physiological Animal Ecology. Longman Pub Group. ^ Nguyen, Thanh Danh; Olufemi E., Kadri; Vassilios I., Sikavitsas; Voronov, Roman S. (2019). "Scaffolds with a High Surface Area-to-Volume Ratio and Cultured Under Fast Flow Perfusion Result in Optimal O2 Delivery to the Cells in Artificial Bone Tissues". Applied Sciences. 9 (11): 2381. doi:10.3390/app9112381. ^ J. K, Lee; H. H., Kung; L. F., Mockros (2008). "Microchannel Technologies for Artificial Lungs: (1) Theory". ASAIO Journal. 54 (4): 372–382. doi:10.1097/MAT.0b013e31817ed9e1. PMID 18645354. S2CID 19505655. ^ a b Glazier, Douglas S. (2010). "A unifying explanation for diverse metabolic scaling in animals and plants". Biological Reviews. 85 (1): 111–138. doi:10.1111/j.1469-185X.2009.00095.x. PMID 19895606. S2CID 28572410. ^ Alberts, Bruce (2002). "The Diversity of Genomes and the Tree of Life". Molecular Biology of the Cell, 4th edition. New York: Garland Science. ISBN ISBN 0-8153-3218-1ISBN 0-8153-4072-9 Check |isbn= value: invalid character (help). ^ Adam, John (2020-01-01). "What's Your Sphericity Index? Rationalizing Surface Area and Volume". Virginia Mathematics Teacher. 46 (2). ^ Okie, Jordan G. (March 2013). "General models for the spectra of surface area scaling strategies of cells and organisms: fractality, geometric dissimilitude, and internalization". The American Naturalist. 181 (3): 421–439. doi:10.1086/669150. ISSN 1537-5323. PMID 23448890. S2CID 23434720. ^ Kils, U.: Swimming and feeding of Antarctic Krill, Euphausia superba - some outstanding energetics and dynamics - some unique morphological details. In Berichte zur Polarforschung, Alfred Wegener Institute for Polar and Marine Research, Special Issue 4 (1983): "On the biology of Krill Euphausia superba", Proceedings of the Seminar and Report of Krill Ecology Group, Editor S. B. Schnack, 130-155 and title page image. ^ Tortora, Gerard J.; Anagnostakos, Nicholas P. (1987). Principles of anatomy and physiology (Fifth ed.). New York: Harper & Row, Publishers. pp. 556–582. ISBN 978-0-06-350729-6. ^ Williams, Peter L; Warwick, Roger; Dyson, Mary; Bannister, Lawrence H. (1989). Gray's Anatomy (Thirty-seventh ed.). Edinburgh: Churchill Livingstone. pp. 1278–1282. ISBN 0443-041776. ^ Romer, Alfred Sherwood; Parsons, Thomas S. (1977). The Vertebrate Body. Philadelphia, PA: Holt-Saunders International. pp. 349–353. ISBN 978-0-03-910284-5. ^ Krause J. William (July 2005). Krause's Essential Human Histology for Medical Students. Universal-Publishers. pp. 37–. ISBN 978-1-58112-468-2. Retrieved 25 November 2010. ^ Meiri, S.; Dayan, T. (2003-03-20). "On the validity of Bergmann's rule". Journal of Biogeography. 30 (3): 331–351. doi:10.1046/j.1365-2699.2003.00837.x. ^ Ashton, Kyle G.; Tracy, Mark C.; Queiroz, Alan de (October 2000). "Is Bergmann's Rule Valid for Mammals?". The American Naturalist. 156 (4): 390–415. doi:10.1086/303400. JSTOR 10.1086/303400. PMID 29592141. S2CID 205983729. ^ Millien, Virginie; Lyons, S. Kathleen; Olson, Link; et al. (May 23, 2006). "Ecotypic variation in the context of global climate change: Revisiting the rules". Ecology Letters. 9 (7): 853–869. doi:10.1111/j.1461-0248.2006.00928.x. PMID 16796576. ^ Fitzpatrick, Katie (2005). "Gigantothermy". Davidson College. Archived from the original on 2012-06-30. Retrieved 2011-12-21. ^ "Marsquake! NASA's InSight Lander Feels Its 1st Red Planet Tremor". ^ venn/A201/maths.6.planetary_cooling.pdf External links Sizes of Organisms: The Surface Area:Volume Ratio National Wildfire Coordinating Group: Surface Area to Volume Ratio Previous link not working, references are in this document, PDF Further reading On Being the Right Size, J.B.S. Haldane
Retrieved from "
large surface to volume ratio means