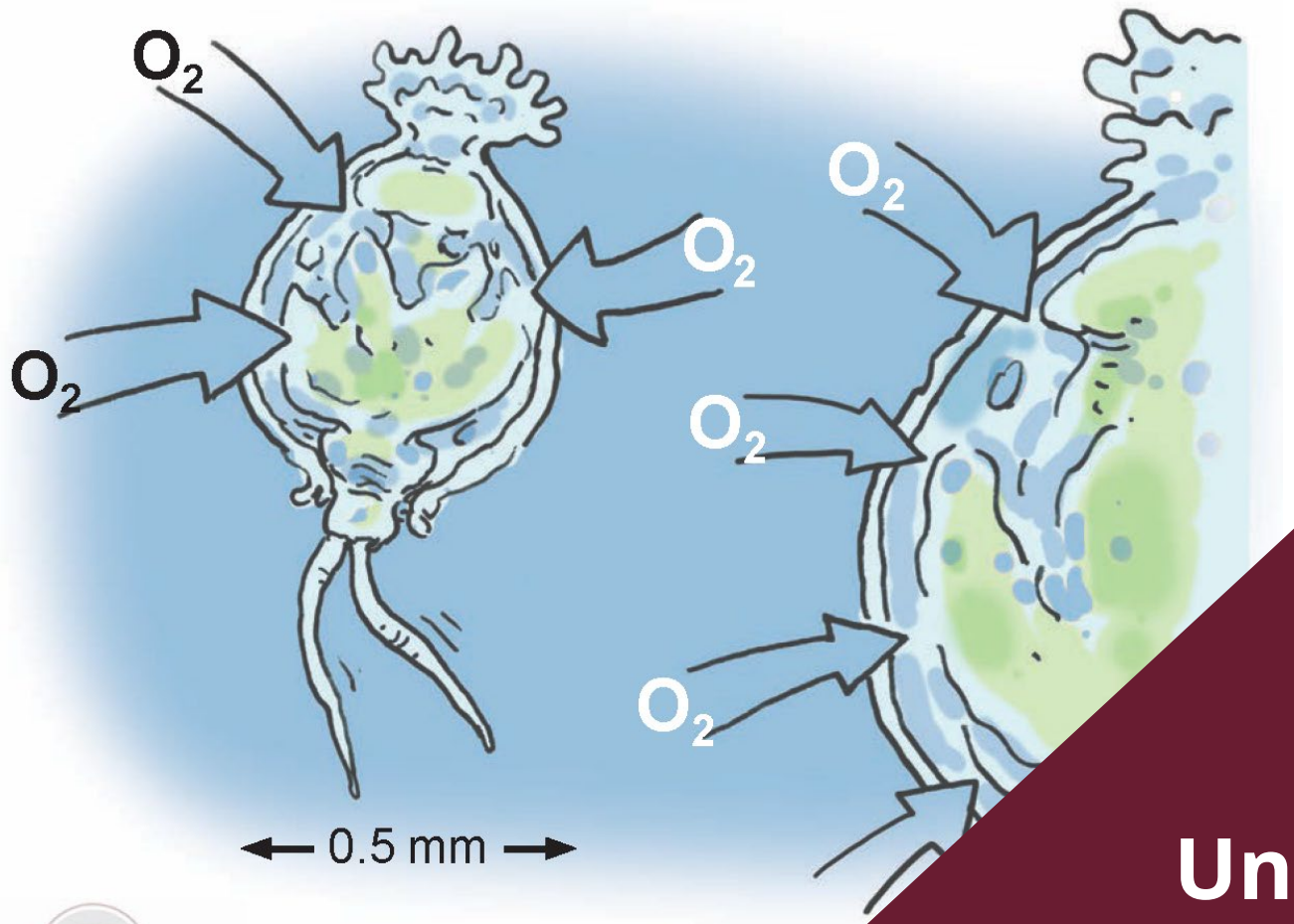
Scaling and Dimensions in Physics: Bridging Growth, Form, and Evolutionary Biology



Dr. Kausik S Das

University of Maryland Eastern Shore

Chesapeake Section of the American Association of Physics Teachers Fall 2023 Semi-Virtual Meeting
October 21, 2023 @
The University of Maryland College Park

❑ Cell phones as formative assessment tools

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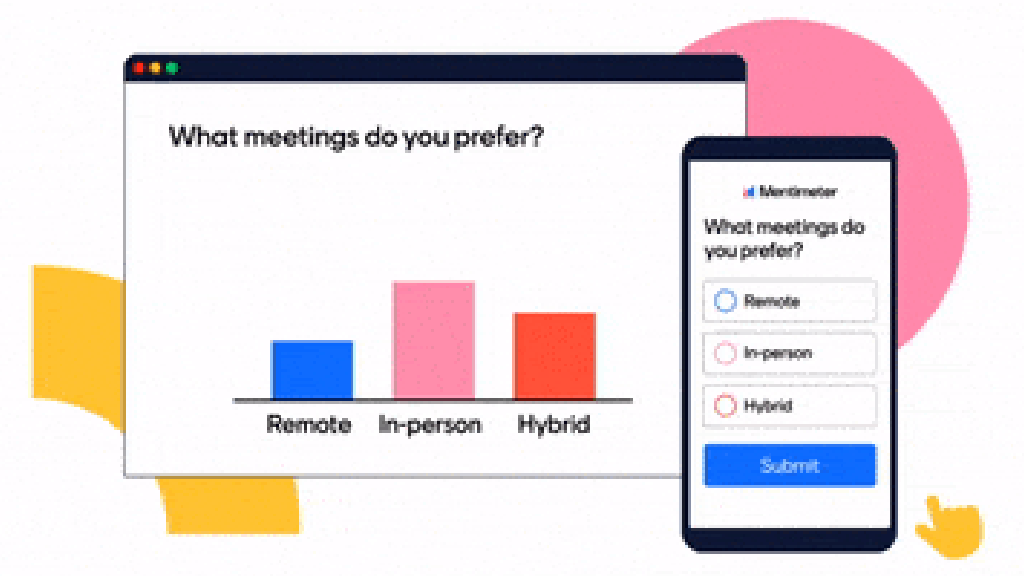


Surface area to volume ratio:

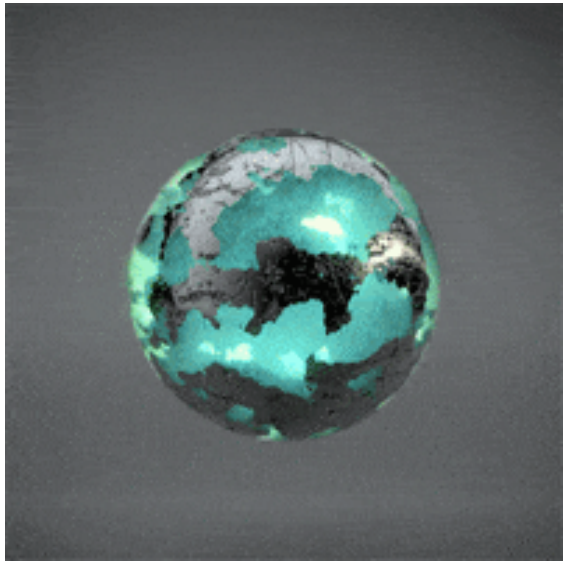
Volume: $V \sim l^3$

Surface Area: $A \sim l^2$

$A/V \sim 1/l$

Mentimeter

Surface area to volume ratio:



Volume: $V \sim l^3$

Surface Area: $A \sim l^2$

$A/V \sim 1/l$

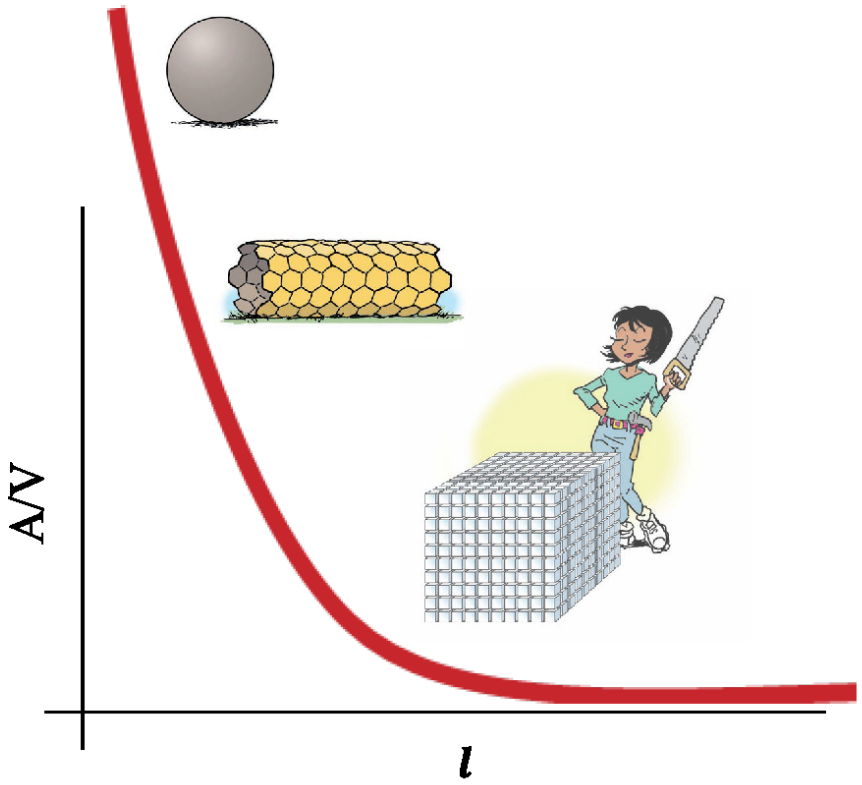
Surface area to volume ratio:

Volume: $V \sim l^3$

Surface Area: $A \sim l^2$

$A/V \sim 1/l$

9b. The surface to volume ratio for a sphere, cylinder or cube is $\sim\frac{1}{l}$, where l is the characteristic length scale. What exactly does it mean by $\frac{A}{V} \rightarrow \propto$, when $\boldsymbol{l} \rightarrow \mathbf{0}$?

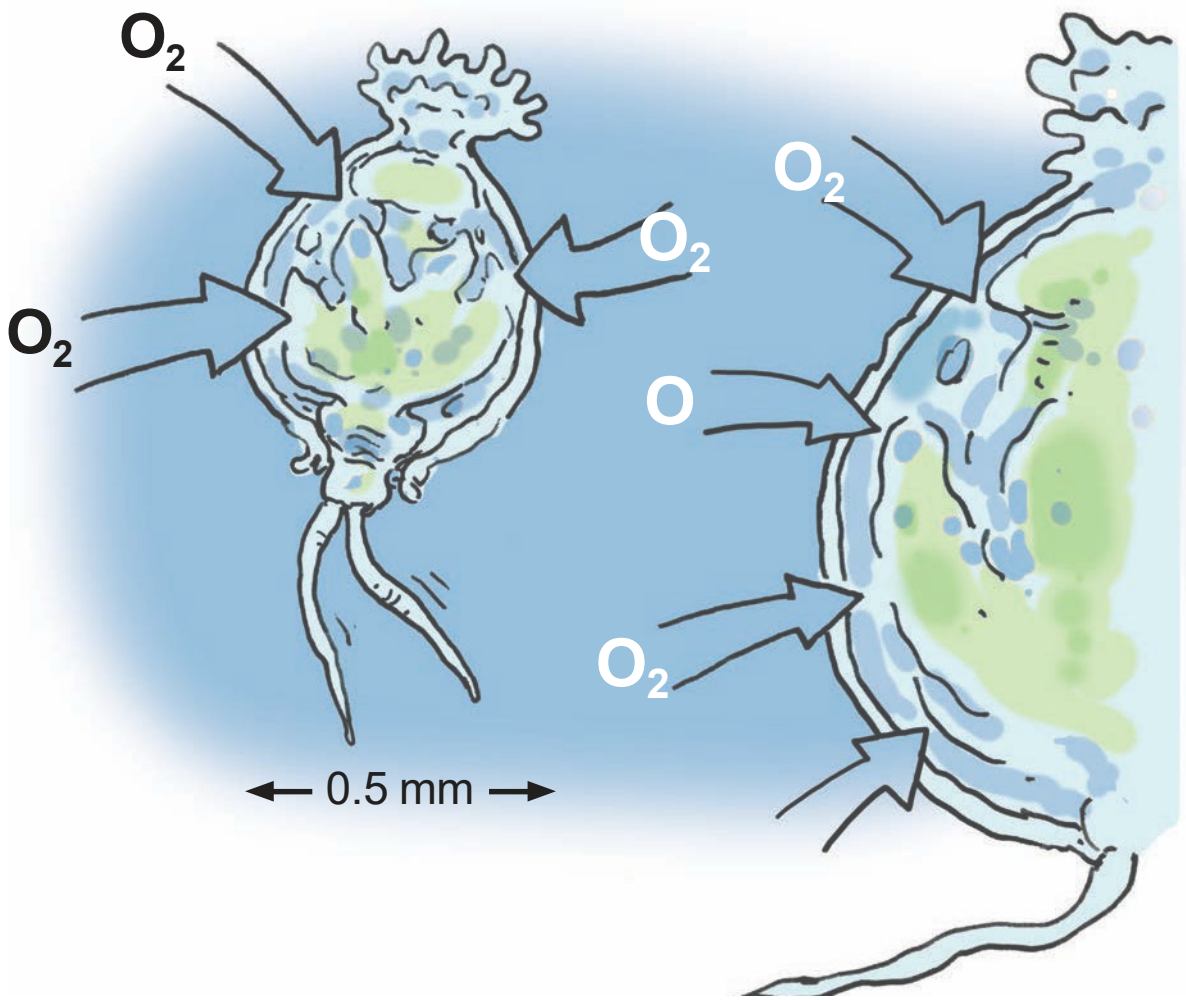


A. It's just a mathematical expression, doesn't mean anything.

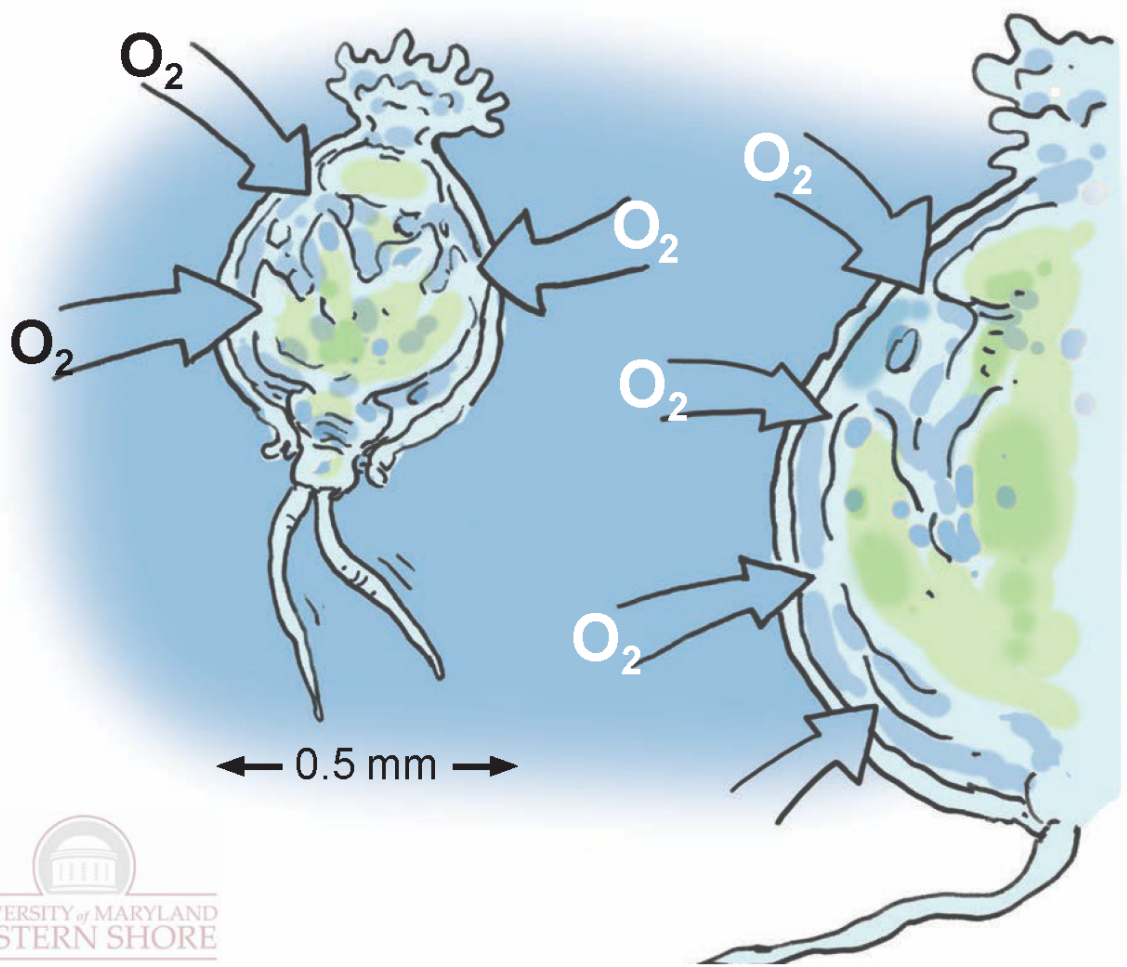
B. It means that if the large sphere, cylinder or the cube is broken down into nanoparticles, nanowires or nanocubes, the percentage gain in effective surface area would be very large.

C. I have no idea.

Rotifers breathe oxygen through their skin!



10. This tiny animal, a rotifer, “breathes” by absorbing oxygen directly through its skin and letting the gas diffuse throughout its body. The rotifer uses all the oxygen it takes in to survive. If the rotifer doubled in diameter, would it still be able to absorb enough oxygen to stay alive?



A. Yes, because the large and small rotifers have the same chemical make-up.

B. Yes, because the larger rotifer has a greater surface area through which oxygen can pass.

C. No, because the larger rotifer has to supply oxygen 8 times the body mass although the surface area increases only 4 times.

D. No, because the oxygen has to travel farther in the larger rotifer.

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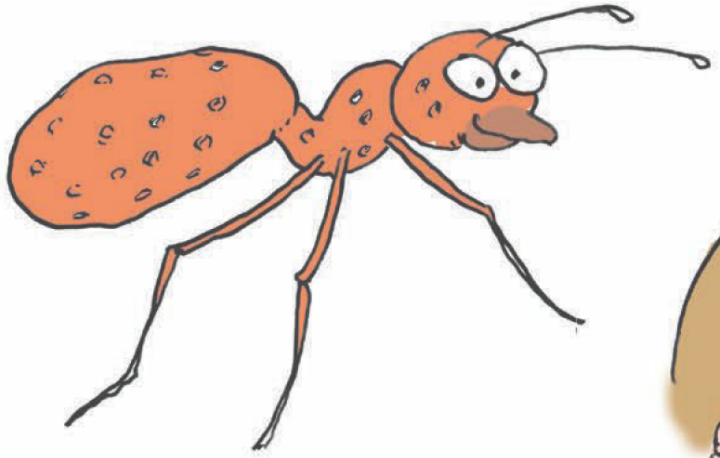
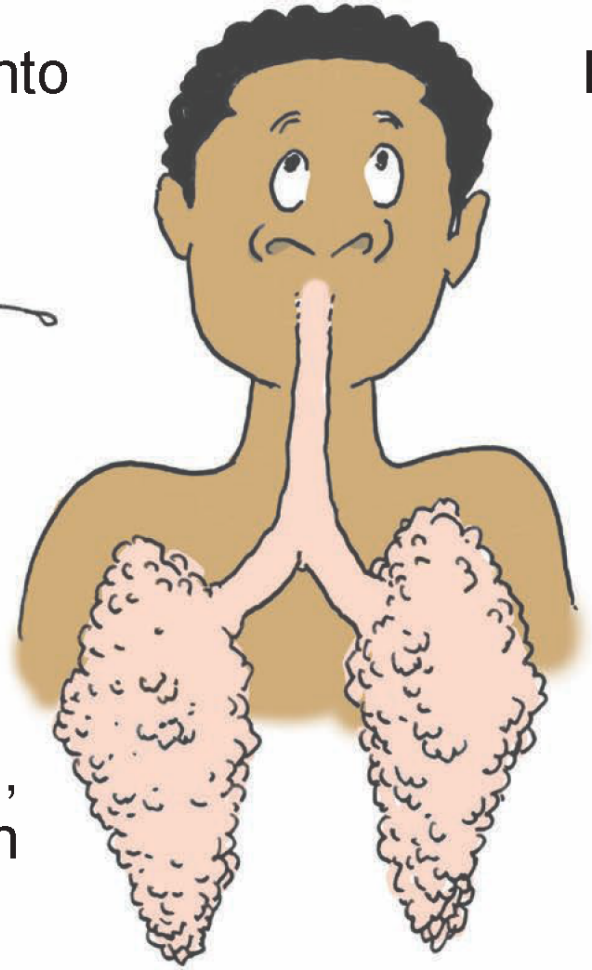
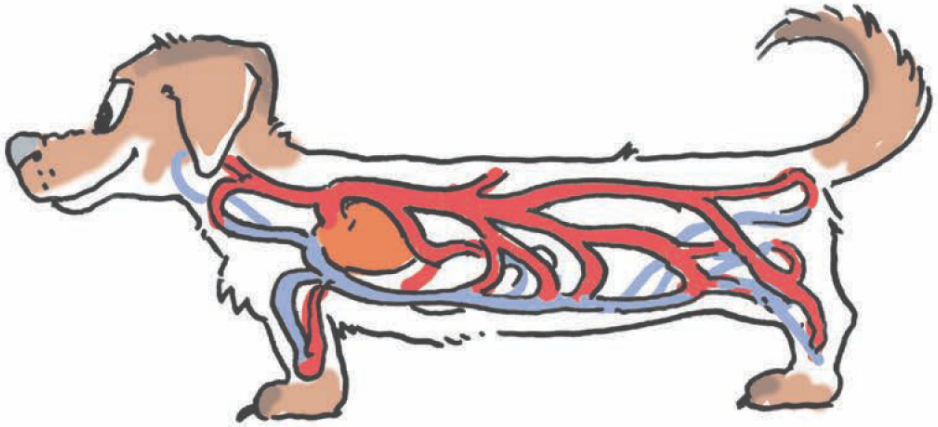
13. Some microscopic animals can supply their own tissues with oxygen by simple diffusion through the skin. For a larger animal, do any of the following evolutionary adaptation help to improve oxygen supply?

A. Many tiny passageways into the body, exposing more surface area to the air.





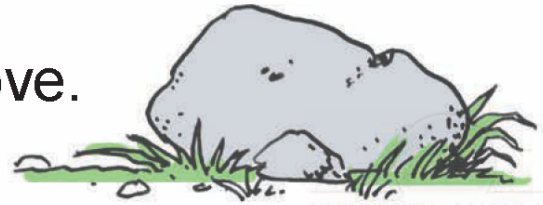
B. A network of blood vessels that move oxygen deeper into the animal.



C. Lungs with a complicated, spongy surface having an enormous surface area.

D. All of the above.

E. None of the above.



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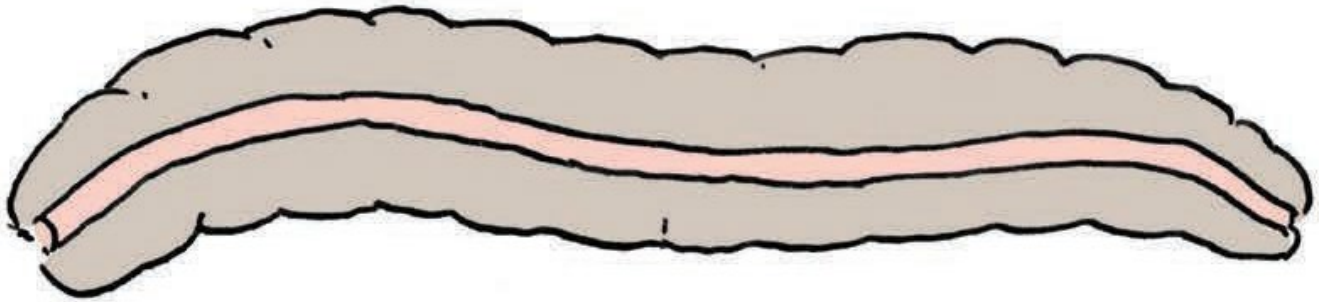
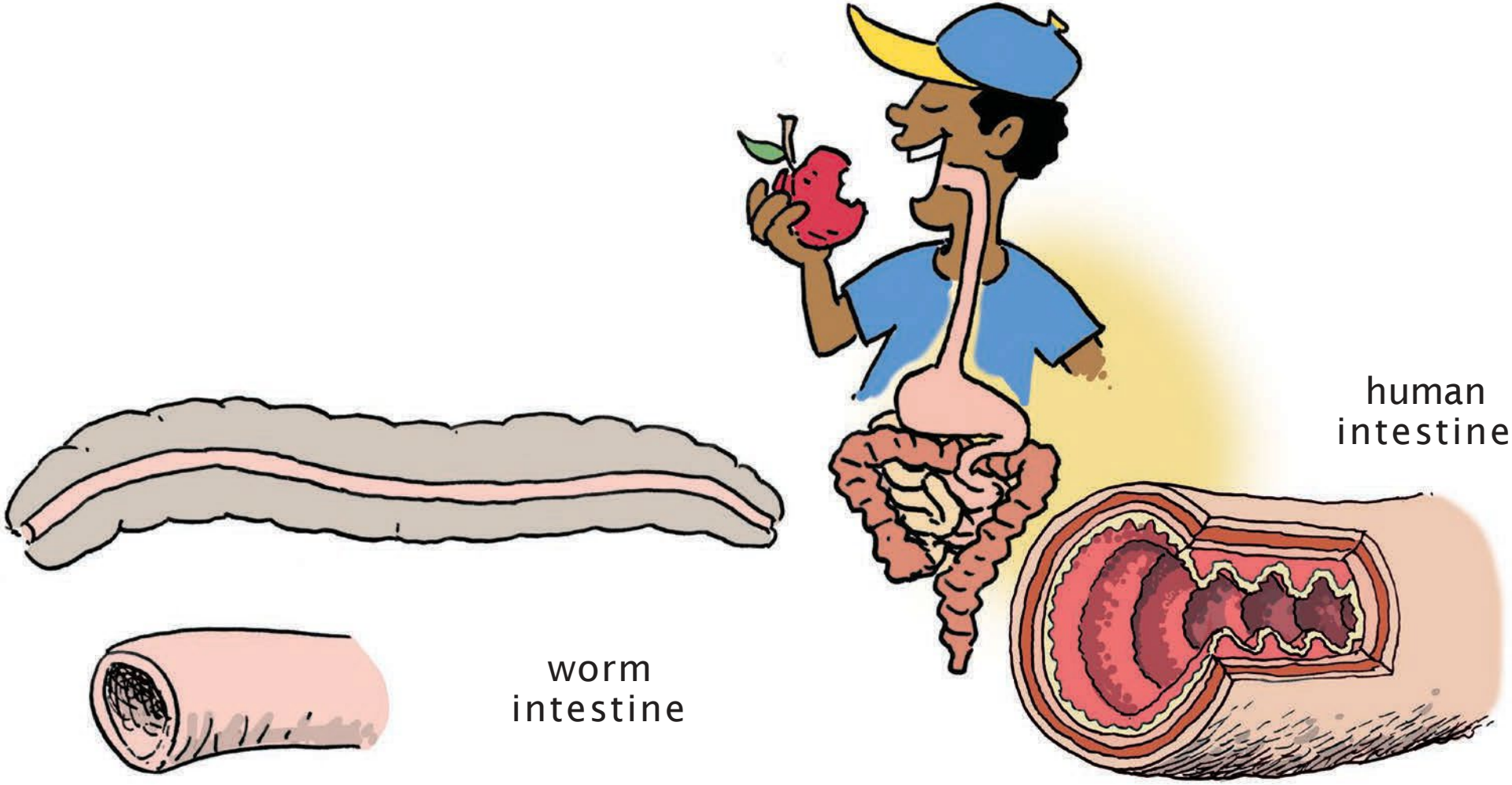
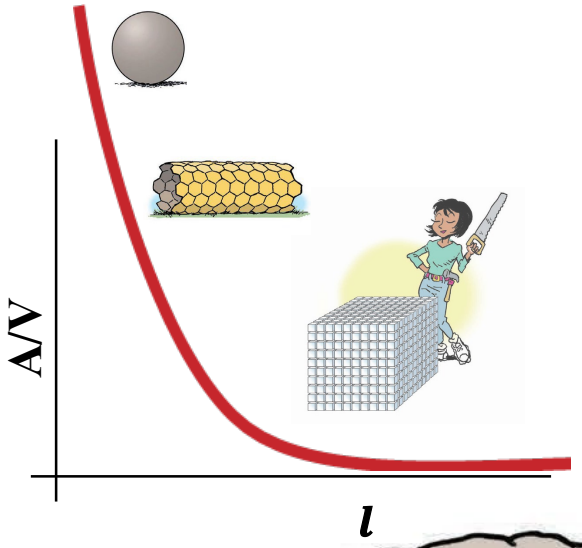
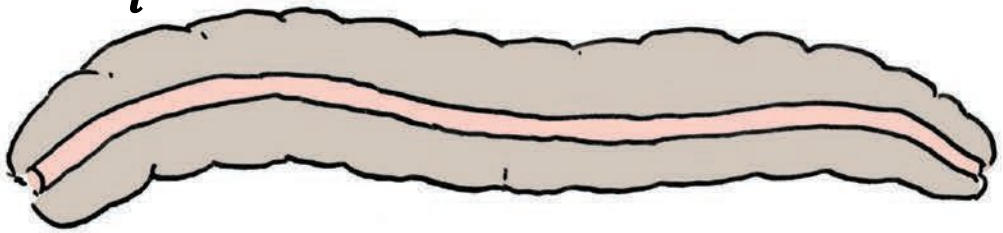
Earthworms have a straight intestine with smooth wall!



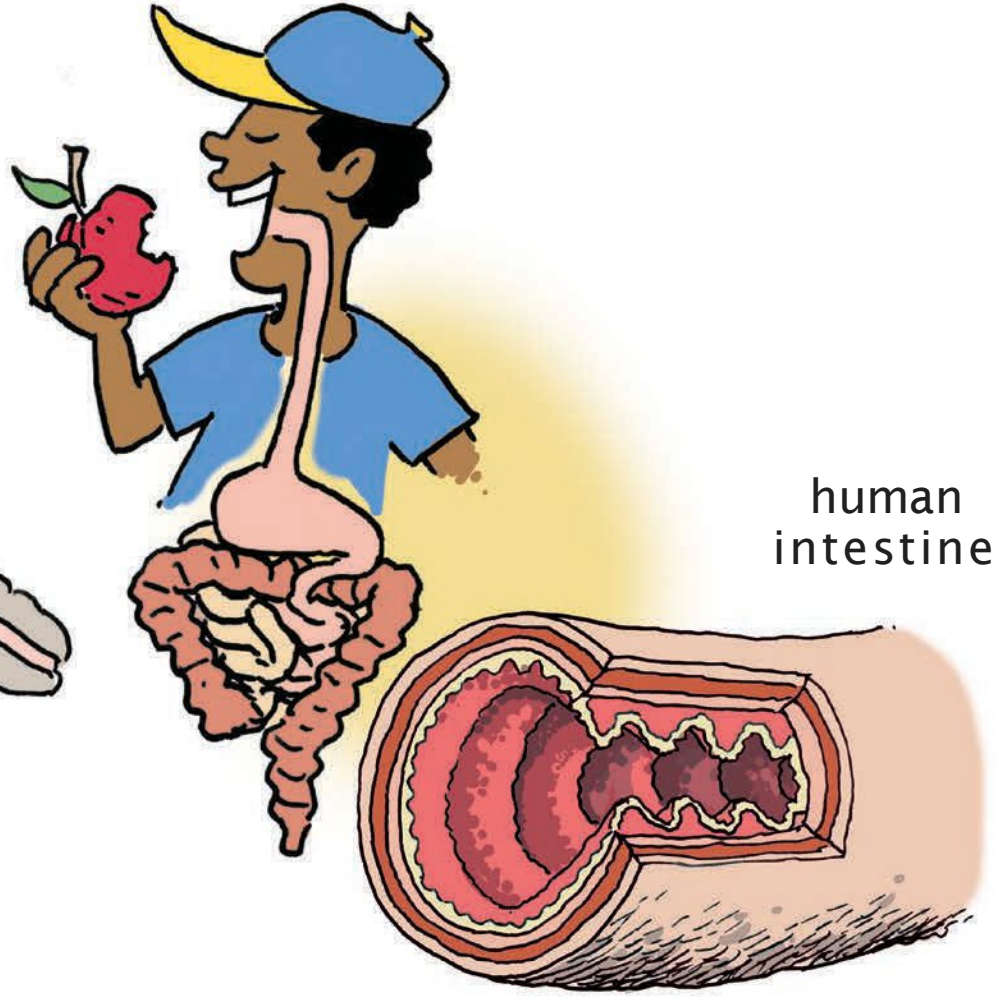
worm
intestine


human intestine
worm intestine

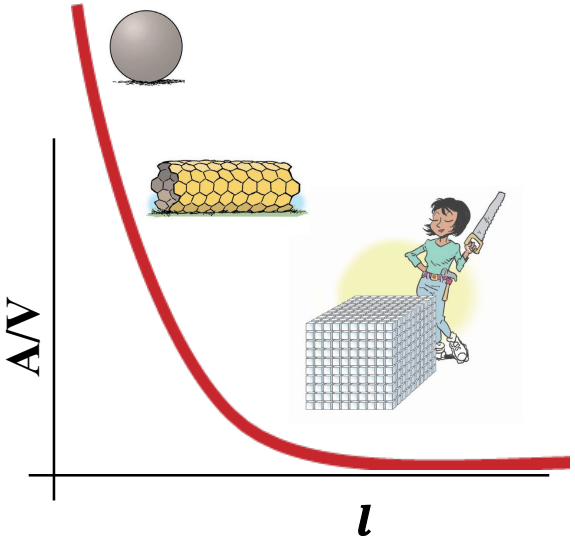




worm intestine



human intestine


A/V
l

5. Steph drinks a magic potion (i.e., large soda, everyday) that makes his body grow to four times its normal height. In fact, all his linear dimensions increase by a factor of four, although his muscle and bone density remained the same. How does this change the **PRESSURE** on his feet and knee joints—that is, the downward force per square centimeter?

A. It doesn't. His feet are also bigger.

B. The pressure decreases by a factor of log 16.

C. The pressure decreases by a factor of 4.

✔ D. The pressure increases by a factor of 4, and his toes and knees start to hurt.

E. The pressure increases by a factor of 160 and his bones break because of his own body weight.

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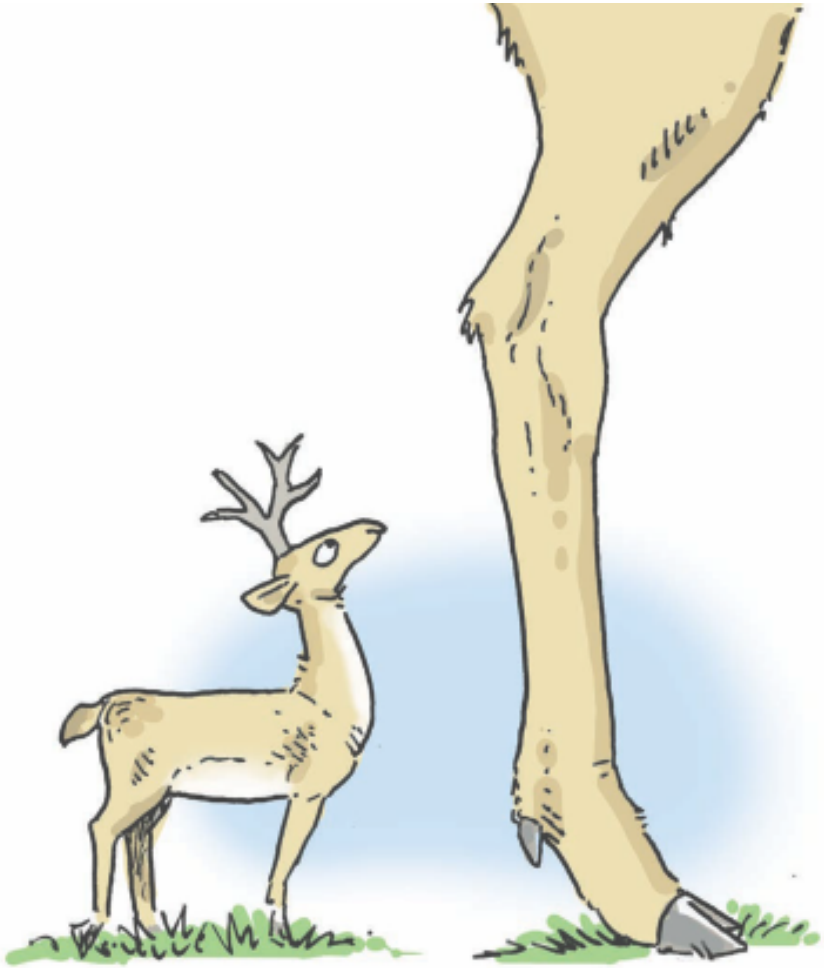

6. A deer magically grows by a factor of 5 in every dimension. Its legs now have 5x their former diameter. Are these enlarged legs thick enough to support the deer's new weight?

A. Yes, because thicker legs are stronger.

B. No, because longer legs are weaker.

C. No, because the increased body weight pressure on each leg is 5x greater and it won't be able to run as fast or jump as high as before.

D. Yes, because the mass of each enlarged leg is 125 times its mass before enlargement.

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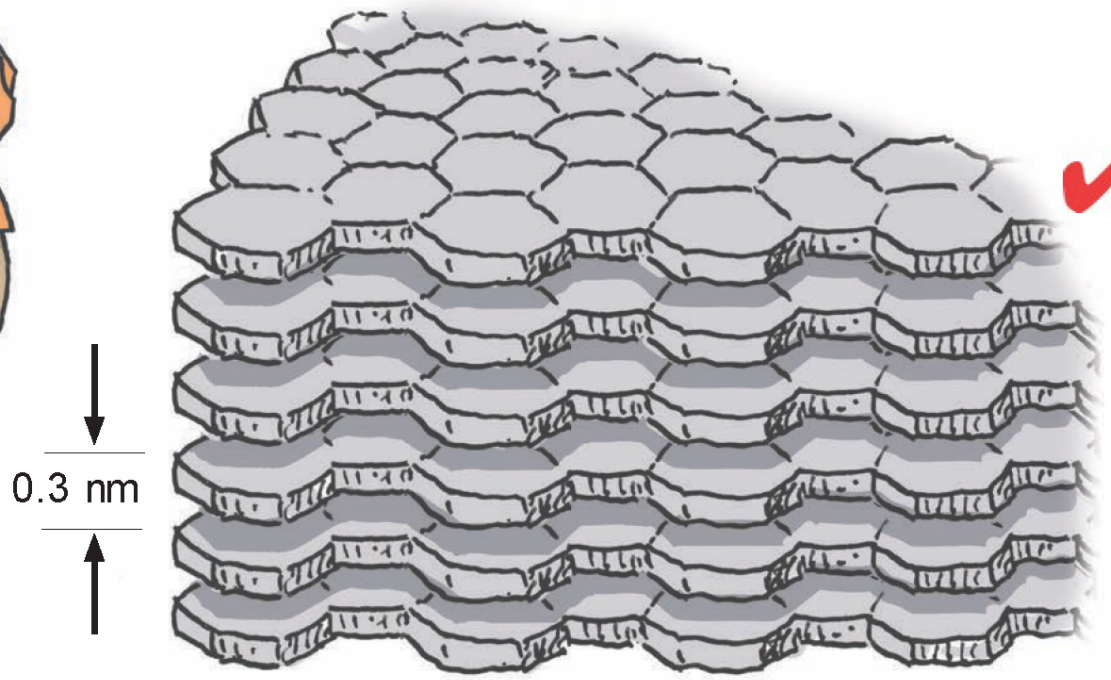
15. Lester has a cubical hockey puck made of **graphite,** exactly 1 cm on a side. Graphite is a layered stack of **graphene** sheets, each a monolayer of carbon atoms. The thickness of one sheet is **0.3 nm** or **3 x 10^{-10} m**. If all the sheets in Lester's puck were peeled off one by one, what would their total surface area be, top and bottom, versus the surface area of the original cube? Ignore the edges of the sheets. A soccer field has nearly 7,000 m^2 surface area.



nanoscale structure of graphite

A. sheet area = 6,667 m^2
cube area = 10^{-4} m^2

B. sheet area = 6,667 m^2
cube area = 6 x 10^{-4} m^2

C. sheet area = 3,333 m^2
cube area = 6 x 10^{-2} m^2

D. sheet area = 6,66,667 m^2
cube area = 6 x 10^{-4} m^2

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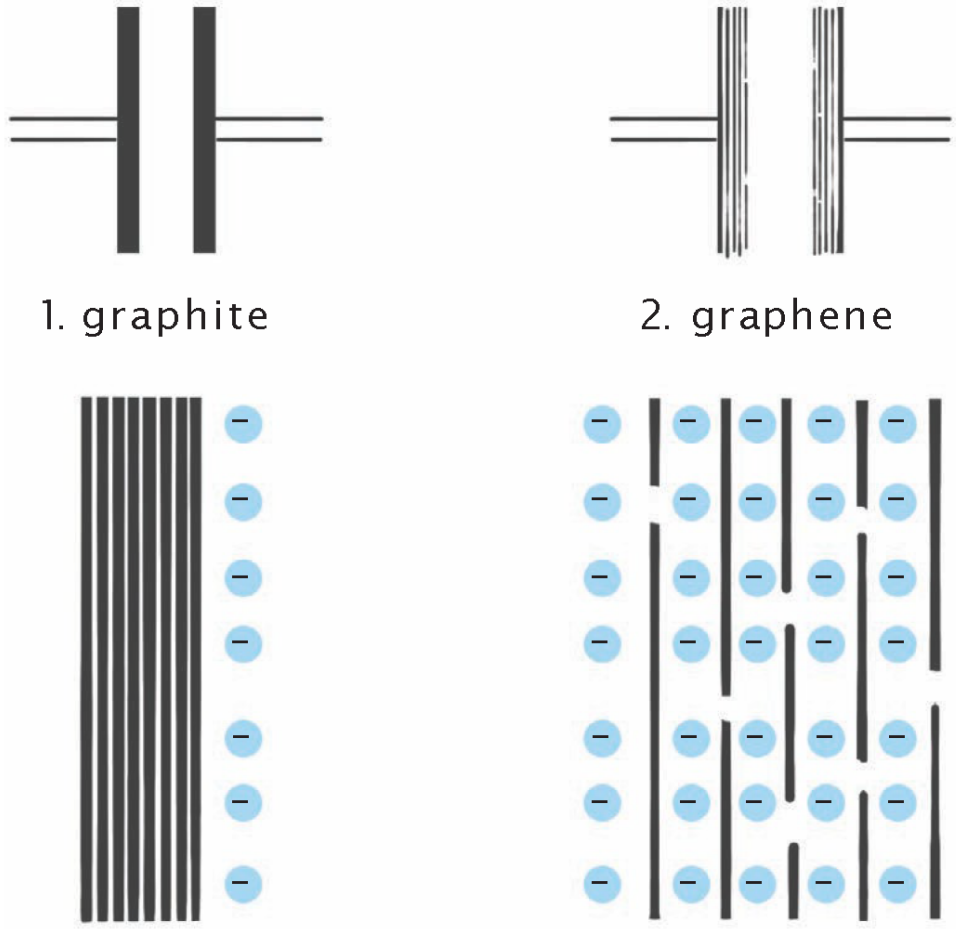
16. Capacitor 1 has plates made of graphite. Capacitor 2 has plates made of loosely spaced **graphene flakes** that came from the same graphite plates. If the mass of the plates and all other parameters are equal between the two capacitors, which one will hold more charge?



A. Both will hold the same charge.

B. Capacitor 1, because its plates are more dense.

C. Capacitor 2, because its plates have more surface area for the charges to access.

D. Capacitor 1, because graphite is thicker than graphene.

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Questions?

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