**The Unsexiest Thing in Science**

Surface area to volume ratio might sound pathologically boring, but it's behind everything from exploding flourand skyscrapers to rock 'n' roll mice.

By [Bernie Hobbs](http://www.abc.net.au/profiles/content/s2109073.htm?site=science/basics)

Now that's sexy! Elephants' wrinkles, ears and telegraph pole legs are graduates of the square-cube school of design. *(photo:wildaid.org)*

Most of the big ideas in science have the decency to confine themselves to one or two disciplines. Evolution is strictly in the biological realm. E=mc**2** wouldn't be caught dead outside physics. And you really need a hammer in your shorts to talk plate tectonics.

But the simple relationship between any object's surface area and volume infiltrates every field of science and engineering.

It's a major factor in the shape and size of everything from plants and animals to skyscrapers. It puts the ceiling on how big a living cell can be, makes otherwise innocuous baking ingredients explosive, and it's the reason your intestines are the size of a tennis court.

It's as essential to design in nature as a black t-shirt and nerd glasses are to design everywhere else.

So what's it all about?

Basically it means that as things get bigger, their inside (volume) gets *more* bigger than their outside (surface area). And it's not just some random relationship. If you double the width of a thing, its surface area gets four times bigger (2**2**), and it can hold eight times the volume (2**3**). Make the thing ten times wider and its area grows 100 times bigger (10**2**), while its volume is 1000 times greater (10**3**). Whatever factor you increase the length, width or radius by, the area increases by that factor squared, and the volume by that factor cubed.



Galileo was the first to write about the square vs cube relationship. In a burst of anti-creativity he called it the square-cube law, and engineers usually use that term. In biology and chemistry, surface area to volume ratio is the preferred lingo, but they're all describing the same relationship. And the reason they all bang on about it is that the relationship holds for all shapes, not just your standard spheres and boxes. Wherever you are, whatever your science, bigger versions of things have relatively small surface areas, and vice versa.

Which begs the question: so what?

And the answer to that is: so pretty-well everything. Starting with chemistry.

Surfaces are where chemistry takes place, and the bigger the surface area the faster that chemical reactions take place. Small things have a big surface area compared to their size, so breaking a big thing down into lots of smaller parts means you can really ramp up the speed of the reaction. Which is why kitchen staples like flour and custard powder make great explosives. Clumped together they're as harmless as any other carb you don't swallow. But add a decent puff of air and a spark and you've suddenly got a crazy amount of surface area (thanks to billions of tiny particles) just waiting to burn in the surrounding oxygen. Every year people are injured or killed by dust explosions in flour mills and granaries — powdered carbs are more explosive than coal dust thanks to their enormous surface area.

Even smaller than incendiary custard powder, nanoparticles take surface area to the extreme. Their minute size (100 nanometres max) means a massive surface area, which makes them way more reactive than their upscale versions. An entire new science — nanochemistry — was born to nut out the full range of their tricks.

**Keeping your cool**

Reactions aren't the only things that happen at surfaces — it's also where heat gets transferred. Everyone knows elephants have got big ears — and it's not because Noddy won't pay the ransom. The big surface area of those hairy grey flaps gives elephants their best shot at cooling down quickly. And all those wrinkles aren't for show — they add extra cooling surface. The bigger an animal (or anything that generates heat) is, the less surface area it's got to lose heat through, so cooling strategies are all-important.

Small warm-blooded animals have got the opposite problem — the square-cube law means they've got a big heat-leaking surface area for their size. They lose so much heat to the environment that they have to eat a huge amount of food each day (up to their own bodyweight) just so they don't die from hypothermia. That huge metabolic rate makes for a high heart rate, and because mammalian hearts are only good for about one billion beats, that cracking heat-replacing pace is what gives mice a very rock'n'roll live fast, die young lifestyle.

But the surface area to volume ratio doesn't just affect an organism as a whole, it controls how big its individual cells can grow, and affects the shape and structure of its organs.

**Limits to growth**

Our cells need food and oxygen delivered, and waste and CO2 taken away. The only way in or out is through the cell membrane, either by diffusion (where small molecules pass through the membrane from the side where they're at the highest concentration), or by being pumped or dragged across the membrane itself. Either way, the size of the membrane compared to the size of the cell is critical.

The amount of 'food' and oxygen that can get into the cell determines how active the cell can be — it needs those materials for its reactions. Big cells have got relatively small membranes, so less material can pass in and out of the cell in any given time. It's that single limiting factor that means regardless of whether you're talking mouse or elephant-sized animals, our cells don't get much bigger than about 100 micrometres.

Animal cells are never too far from a capillary — a very skinny blood vessel with an incredibly thin wall. The long skinny tube shape of capillaries gives them a big surface area compared to their volume, which makes them ideal for leaking oxygen and nutrients to the surrounding tissues, and sucking up waste. And they get that food and oxygen from two organs that punch way above their weight when it comes to surface area per unit volume.

Our lungs are ridiculously intricate layers of tiny sacs called alveoli that are just one cell layer thick. If you could unravel a pair of lungs you'd have extreme patience, messy clothes and a single membrane that would cover a tennis court, and then some.

But that's nothing compared to your intestines. Inside your gut is about 300 m**2** (about three and a half tennis courts) of small and large intestine — not bad for something that looks like about 8 metres of sausage casing.

Like your lungs the intestines are a single cell layer thick, so that nutrients and water can diffuse across them. But instead of sacs, the intestine is one crazy microscopic fingerland. It's all peaks and valleys with no plains in site. These finger-shaped projections are called microvilli, and they're a tiny version of the classic surface area maximizing shape. The same strategy gives jellyfish tentacles, single-celled organisms and pom poms maximum area bang for their volume buck.

There's one more major area where surface area/volume has an impact — in load bearing. Whether it's in the thickness of a leg bone or the choice of material in a multi-storey construction, scaling a model up or down isn't as straightforward as the fifty-foot woman makes it seem.

**Scaling: Galileo one, Gulliver nil**

If Gulliver had really visited a land of giants, they wouldn't have looked like scaled up versions of him. If they did it would have been broken legs all round.

Unless you're made of gas any significant change in your volume is going to really stack on the kilos. The square cube law means that if you doubled a person's height they'd have four times the area but would weigh about eight times as much. To support all that newfound self, their leg bones would need to be four times wider than the original model, not just double the width. You'd forgive Gulliver the odd culturally inappropriate "I've seen better legs on pianos" when he hit the land of the giants.

At the other end of the scale, Rick Moranis's newly shrunken kids should have been able to leap tall furniture and lift things way heavier than themselves. (Surface tension would have played havoc with their circulatory, respiratory and digestive systems, but for those few seconds they did remain alive they would have been superheroes).

Shrinking the kids to one tenth of their height would cut their weight by a factor of a thousand (10**3**), but the cross-sectional area of their muscle (and bone) would only be one hundred times smaller (10**2**). That means they would have been ten times stronger for their size post-shrinkage. But still no match for a passing ant that could not only breathe, but lift something fifty times its weight.

The square-cube law makes scaling a staple of engineering. It's the reason tall buildings rely on steel, not just more concrete (steel is about 25 times stronger). And why those huge airbuses have got much bigger wings than jumbos — the A380 might only be a few metres longer and wider than a 747, but it weighs twice as much.

What it lacks in sexiness, surface area to volume ratio more than makes up for in global reach and power. Give it a phone hacking scandal and a paywall and it's Rupert Murdoch.

*Thanks to Dr Terry Walsh, Head, School of Biomedical Sciences at* [*Queensland University of Technology*](http://www.hlth.qut.edu.au/bio/)

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“The Unsexiest Thing in Science” Reading Review

1. Describe the relationship between surface area and volume as objects get bigger. What happens as you make objects smaller?
2. Explain why elephants have large ears, in terms of surface area.
3. How does surface area limit cell size?
4. Explain how surface area-volume relationships would affect giants or miniature people.
5. Describe 1 thing from the article that was most interesting to you and why.