Problems for mystification, enlightenment, or, if using *The Life of a Leaf* for teaching, assignments or exams

Notice that few of the questions deal directly with leaves. Again, the book intends to stimulate thinking about a far wider range of phenomena than one might consider botanical, in particular ones hinging on how the physical world impacts organisms such as ourselves.

A set of possible answers can be had by e-mailing svogel@duke.edu. Please give a little information about yourself so I can avoid dispensing answers to students taking courses that might use the problems.

(Initial numbers indicate relevant chapters in the book.)

(1) A sedentary human has a metabolic rate of about 70 kilocalories (kcal or Cal) per hour, or about 80 watts. Traditionally, the season for theater, concerts, opera, and so forth began in the fall and extended though the spring. How might that datum have determined the latter condition?

(1) When teaching introductory biology, we ordinarily introduce genetics with just those functionally trivial examples mentioned—whether ears will wiggle or tongues will curl, whether or not earlobes hang down, the color of eyes. Why do we choose these for attention, rather than picking features that matter a lot more?

(2) In otherwise forested country, the sight of hawks or vultures soaring in circles, often with one bird above another, commonly indicates the location of a freshly plowed, paved, or otherwise bare patch. Consider what has been said about light, convection, and energy and suggest an explanation for the phenomenon.

(2) One often hears comments comparing the low efficiencies of our solar collectors with the marvelously better performance of photosynthesis in plants. Dig around the web and see whether these comments reflect reality.

(3) Marek et al. (*The American Biology Teacher*, 56, 74-77; 1994) discuss how student misconceptions about diffusion can be eliminated. The description of diffusion they claim that students fail

to comprehend follows. Comment on the real problem with the statement they claim is misunderstood.

> A 10-gallon glass container is full of clear water. Several drops of a dark blue dye are dropped on the surface of the water. The dye begins to swirl, then spreads throughout the water. Eventually the water changes from colorless to light blue.

(3) What would the beakers on page 50 look like if one started with a mixture of red and blue colorants, with one colorant consisting of molecules considerably larger than the other?

(4) Yes, even gases have viscosity. Can you suggest a simple set-up to measure the viscosity of air? A good starting point is the Hagen-Poiseuille equation, given in the footnote on page 109.

(4) Many aquatic animals both respire (exchange dissolved gases) and suspension feed (extract edible particles) using gills. Some gills are purely respiratory, but for some the (original?) respiratory function is just an easy side issue, with gill dimensions optimized for particle capture. How might rough calculations of Péclet number help one distinguish the two in, say, some creature dredged up from the abyss?

(4) A very soft flatworm that lives in a stream is aware of the no-slip condition. It manages to find a shallow depression atop a very smooth rock, one just large enough so the worm exactly fills it. The worm figures that by not protruding at all it can avoid entirely the drag of the current. But it finds that it's still pulled downstream by the flow of the stream. How can the worm still be subjected to drag (ignore any lift) from a flow when the flow is zero everywhere on its surface?

(5) In a negative feedback system, information about the system's output is fed back to the input; the system detects any difference between the output state and some reference state and takes action to reduce that difference. A person using an electric blanket makes up such a system—if you get too hot, you turn down the control; the reference state is whatever gives optimal comfort. Dual-control electric blankets allow each person to control the half-blanket that the person lies beneath. Describe in terms of feedback (and, if need be,

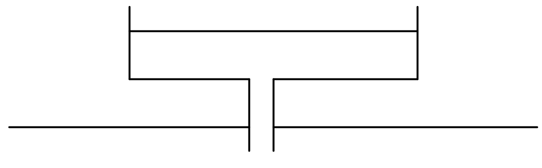
expletives) what would happen if in such a dual system, the wires leading to the controls (beneath the bed) were crossed.

(5) Many, perhaps most, plants respond to modest increases in ambient carbon dioxide by increasing their rates of growth. So adding the stuff to our atmosphere sounds like a good thing—our crops will grow faster, and the build-up of carbon dioxide will be controlled in a proper negative feedback loop by their increased activity. Where's the flaw in this reasoning? Or, put another way, what other aspects of the feedback process must be considered?

(6) A human can blow air out of the lungs at a maximum pressure of about a third of an atmosphere—about 30,000 pascals or 5 psi. How long a piece of a twig with vessels 0.5 mm in diameter can you blow through when trying to make bubbles in a glass of water, as suggested on page 113?

(6) A human male can suck water at a maximum pressure of about minus 0.1 atmosphere. (Females do about 0.07 atmospheres.) How long can a soda straw be if used vertically? More interestingly (if less close to home) how deep in a body of water can you hide while breathing through a snorkel pipe that extends upward to the surface? This last point, by the way, was invoked by Knut Schmidt-Nielsen as a strong argument against the idea that brontosaurus could use its long neck as a snorkel; in fact the practical length for a snorkel is about half the calculated maximum depth you've just calculated.

(6) or (9) An organism wants to maintain a small reservoir of water above a main body of water to provide a fish-proof incubator for its eggs. Why couldn't it use the arrangement just below, in which a capillary tube or tubes (thin enough to permit raising water the requisite distance) leads up to its reservoir?



(7) The hand-operated pumps used for the high-pressure tires of racing bicycles have pistons with small diameters, while the pumps used for lower-pressure automobile tires have wider pistons. The bicycle pumps can be pressed (!) into service for automobiles, although they work slowly, but automobile pumps just won't do for racing bicycles. Why not?

(7) Does commercial piping follow Laplace's law? Go off to a large hardware store and examine (preferably with calipers) the walls of PVC pipes of various diameters but with the same pressure rating (typically given as "Schedule 40," etc.). How does wall thickness vary with overall internal diameter. Or consult some catalog that gives the weights of standard ten-foot lengths and derive equivalent information.

(7) Aerosol shaving cream comes in little cans designed for travel (and for alarming airport security) as well as two large, ordinary sizes. A large can is 65 mm in diameter and 120 mm in length; a little can is 35 mm in diameter and 95 mm long. What's the ratio of the amounts of shaving cream in the two containers, assuming Laplace's law is completely applicable and the cans are made of the same material? (And why is it harder to meter out an appropriate amount from the smaller can.)

(7) At least one feminist tract asserts that many food cans have been deliberately given the cylindrical shape of the human penis in order to force human females, who do the shopping and food preparation, to perform some kind of symbolic sexual act when handling such cans. Suggest a non-sociological, non-<u>male</u>volent alternative explanation for the fact that both items are cylindrical.

(8) You want to charge up the batteries of your 20 kilowatt electric car with 4 square meters of solar panels mounted above the roof; the panels are 25 percent efficient. What's the ratio of full-sunlight charging time to full-power driving time that you can expect?

(8) Sketch the layout of a house that avoids direct, overhead sunlight with the cactus's trick, but one that takes it one step further by blocking sunlight with solar panels, another step further by using the warmed panels to generate ventilating air movement, and yet another

step by arranging so the convective movement reverses at night, with the cool air used to cool some internal heat storage medium.

(9) Okay, so what is the magnification of the photograph in figure 9.1? And, assuming the glass is close to perfectly hydrophilic, what is the contact angle for polyethylene?

(9) Plastrons work well as gas-exchange augmenters in aquatic insects and, it seems, some submerged leaves. But the insects are small and the leaves are thin. How might the problems of scaling affect their utility? Consider both, as here, how scaling apparently limits the upper useful size of the system, and then how it might limit the lower useful size of the system and organisms that can make use of plastrons.

(10) The average temperature of the surface of the earth is about 10º C. A considerable amount of water cycles back and forth, seasonally, between liquid and solid states. Presumably as the temperature moves away from the freezing point, less cycling will happen. What might be the general consequences, not of less solid water *per se*, but of less water seasonally shifting between states?

(10) A mixture of alcohol (ethanol) and water provides some protection against power failures for food freezers (page 187). Why, then, do we no longer (as we once did) use such a mixture for the antifreeze in automobiles? Ethanol is cheap, has a lower molecular weight, and is less toxic than ethylene glycol. For that matter, why don't we use methanol, also cheap and an even smaller molecule?

(11) Gibbons both walk on their feet and "brachiate," hand over hand. The weight supported is the same in either case. Suggest why it is functionally reasonable for their arm bones to be more slender than their leg bones. Arm bones and leg bones have about the same length.

(11) Our favorite materials take compressive stresses best—bricks, cement, etc.—or withstand compressive and tensile stresses about equally well—metals, wood, plastics, etc. We avoid pure tensile loading and use the tension-resisting character of materials such as metals to help bear bending and torsional loads.

Loading in tension can improve weight economy—bearing a load in tension rather than in compression usually takes less material. The longer the structural element, the greater the advantage of tensile loading.

Loading in tension has at least two disadvantages. First, connections between elements are harder to arrange—bricks may be held in place by minimally adhesive mortar, but the stays of a sailboat's mast or the suspenders of pants or suspension bridge need fancy attachments. Second, tensile structures are typically less stiff (even if equally strong) than structures designed to take compression.

Natural structures load many of their elements in tension—nature seems to have little trouble attaching a tendon to a bone or a muscle to a mollusk shell. She cares more about strength than stiffness and (especially where locomotion is involved) cares a lot about weight economy. Sometimes she makes only tensile components, using that ubiquitous environmental stuff, water to take compression. The resulting hydroskeletons are strong, versatile, and cheap in materials but not very stiff.

Imagine a most peculiar technology. It has no solid compression-resisting material—it can't make or obtain any solid material that can withstand being pushed against, and compression can be taken only by liquids or gases. It has fluids that won't freeze at any temperature it encounters, so freeze-thaw damage is of no concern. Your task is to describe this world of ropes, sheets, and tubes, together with the culture of the creatures that have created its devices, creatures themselves built and living within its constraints. They're not primitive—they have buildings, engines, vehicles, sports, and even weapons. They have fibers and membranes that stretch to many times resting length and others that are nearly inextensible; they have some materials of high resilience and others in which the work of extension mainly heats them. But they know nothing of bricks and mortar, of I-beams and simple hollow columns, nor of wooden studs and nails.

Let's assume that the gravitational acceleration, ambient temperatures, the properties of water and of tensile proteins, etc. are as we know them. Let's assume also that the physical environment is much as we know it—flat and hilly land, still and moving water. But we'll rule out using clay, stone, etc. as building materials.

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How about a thousand or so of your best words to flesh out the salient features of the artifacts of this civilization? Perhaps the task will work best if you focus a bit on specific items of the world about whose arrangements you feel most insightful. You're free either to describe the world as an explorer might or to create "literature" by putting matters into a proper science fiction plot.

(12) Palm trees must be the world's best trees when it comes to taking wind high up with minimally-rooted trunks. You wish to determine the drag versus speed curve for a tall palm tree in winds up to storm velocity. No wind tunnel is available that's both large enough and fast enough for the task. But you own a winch with a built-in tension gauge, an anemometer, and a camera. How might you manage this heroic bit of never-before-attempted (yes, really!) biomechanics with minimal damage to the tree?

(12) Imagine that the gravity on earth drops by half, with no other changes to climate, atmospheric composition, and so forth. Given enough time for evolution to have its say, what might you expect to happen to tree heights? Will they increase, or (paradoxically) decrease, or will some kinds become higher and others lower?

(13) The book (pages 246-47) considers how leaves withstand the damage from the holes herbivorous insects produce. Might some leaves go a step further, adapting their form and operation to derive positive benefit (= selective advantage) from having a caterpillar eat some holes part-way through the growing season?

(13) Some countries, initially Australia, issue "paper" money that's really printed on a sheet of a polymer. (The preferred term, "polymer," carries less pejorative connotations than "plastic.") Despite the fact that paper is a nicely fibrous composite, polymer bills do far better at resisting tearing. What might be the basis of their superiority?

(14) The pyramids of ancient Egypt were built of stone blocks weighing about 2.5 tons each. The great wall of China was mostly built of cast blocks of weights not much different from those of our present

cement blocks. Suggest how the cost accountants and engineers of both the pharaohs and the emperors might both have made rational choices.

(14) We biologists find nature's designs so impressively diverse and so worthy of our attention that we rarely ask about things she doesn't. But what doesn't occur may be almost as revealing about the nature of natural design as what does. As striking as any omission is that of metallic materials—we know of no instance in which a metal or metal alloy is used as a material for any mechanical purpose. The omission is even more startling when we recognize both the number of metals used in ionic form or as parts of compounds and the apparent ability of every cell to process metal atoms in its metabolic machinery.

Why might nature not use metallic materials? Please explore the possibilities, explaining, picking, and choosing among the various levels of likelihood. Feel free to use any source—written, electronic, or personal—or no source at all beyond your own cerebrations.