Biology 427 Biomechanics
Lecture 15. Basic fluid dynamics: defining properties of fluids.

- Where we have been and where we are going
- The formal definition of a fluid (revisited)
- Viscosity: depends temperature, concentration of dissolved or suspended solutes, even shear stress (non Newtonian characteristics)
- Viscosity: feeding on fluids and pumping fluids
- Surface tension

Solid and structural mechanics: stress and strain distributions, movements of bodies and their parts in response to muscle forces and gravity.

Fluid dynamic issues underlie:

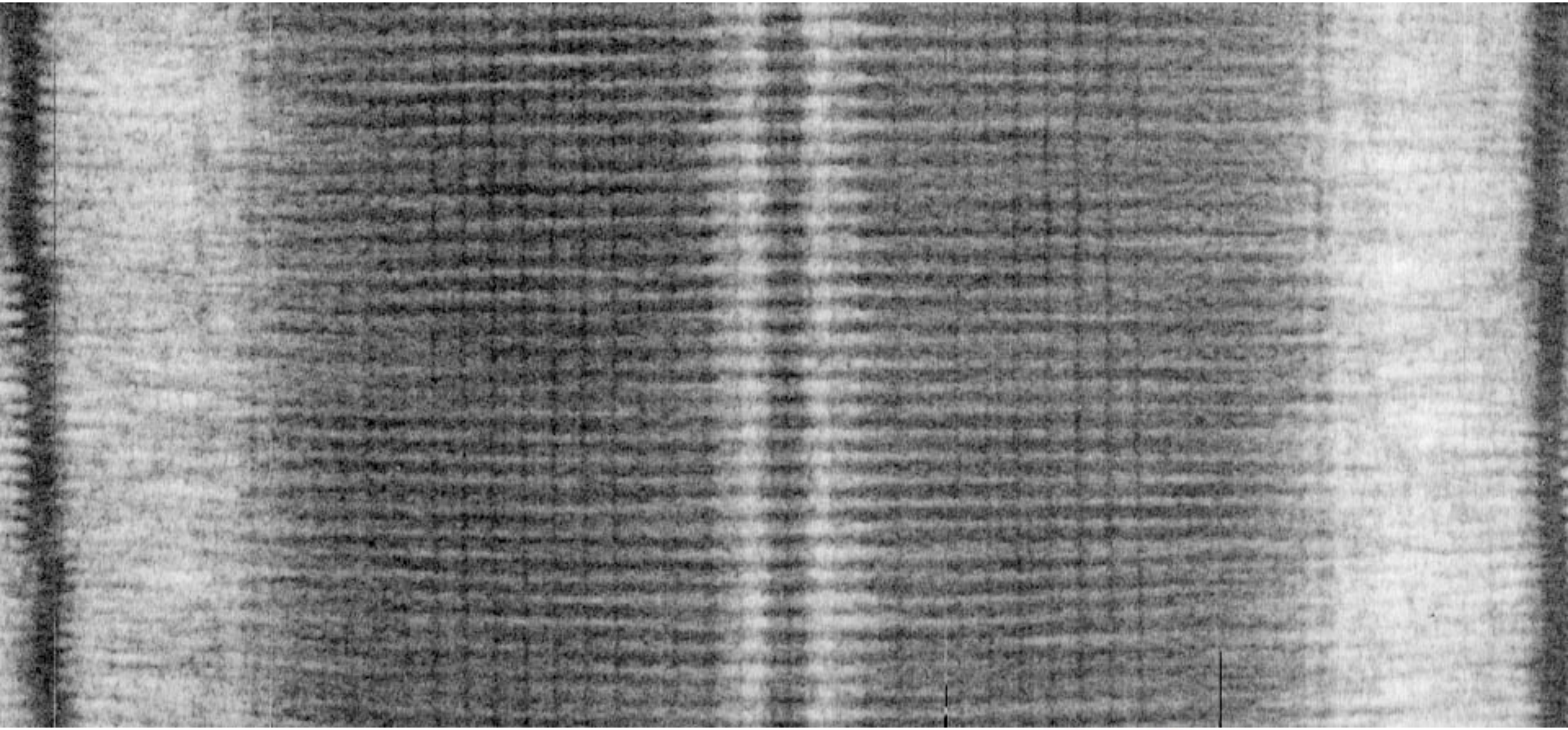
- Internal flows (blood, respiratory flow, intracellular flows liquid food…)
- External flows (swimming, flying, running in air and water)
- Wind and water forces on sessile creatures
- Dispersal (fungal spores, larvae in the ocean…)
- Transport of nutrients and heat to and from biological surfaces (CO_2, H_2O, O_2 …)

Definition: A fluid (gas or liquid) deforms continuously under an applied stress.

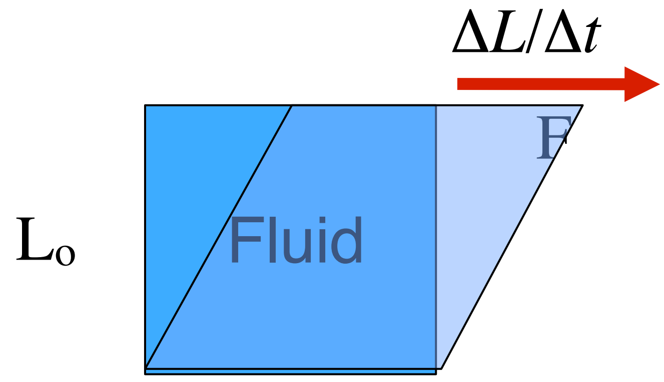
The continuum hypothesis will dominate our studies: density, temperature, momentum, energy … all vary continuously. We can calculate their spatial derivatives if we need to do so.

But, when the spatial scale of the problem (L) is of the order of the mean free path of the fluid molecules (λ), we have a problem. Knudsen number $= \lambda/L$. This underlies many subcellular problems and remains rather unresolved!

5-10 nm gap filled with cross bridges
water has a mean free path ~ 0.3 - 1 nm



Definition: A fluid (gas or liquid) deforms continuously under an applied stress.



$$\tau = \mu d\varepsilon/dt$$

$$du/dy = d\varepsilon/dt$$

$$\tau = \mu du/dy$$

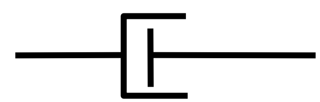
dynamic viscosity of a fluid

Newton's Law of Viscosity

$$F \sim \Delta L/\Delta t \sim dL/dt$$

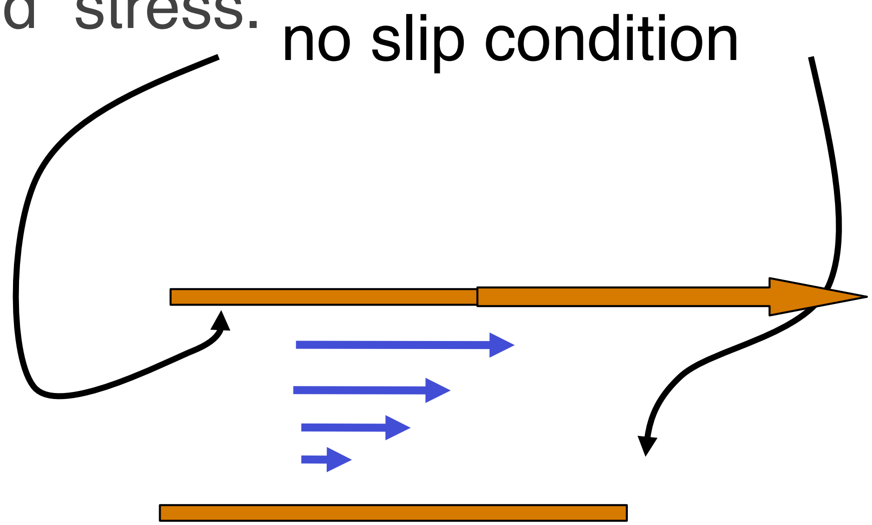
$$\tau \sim d\varepsilon/dt$$

$$\tau = \mu d\varepsilon/dt$$



dashpot

Definition: A fluid (gas or liquid) deforms continuously under an applied stress.



$\tau = \mu du/dy$

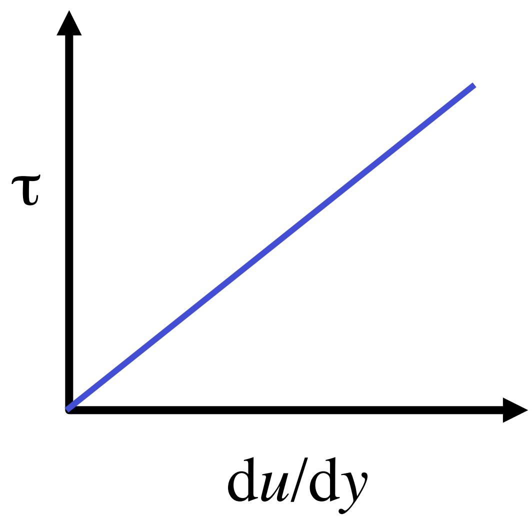
dynamic viscosity of a fluid

Newton's Law of Viscosity

ν= kinematic viscosity

$= \mu/\rho$

$\tau = \nu\, d(\rho u)/dy$



viscosity depends on

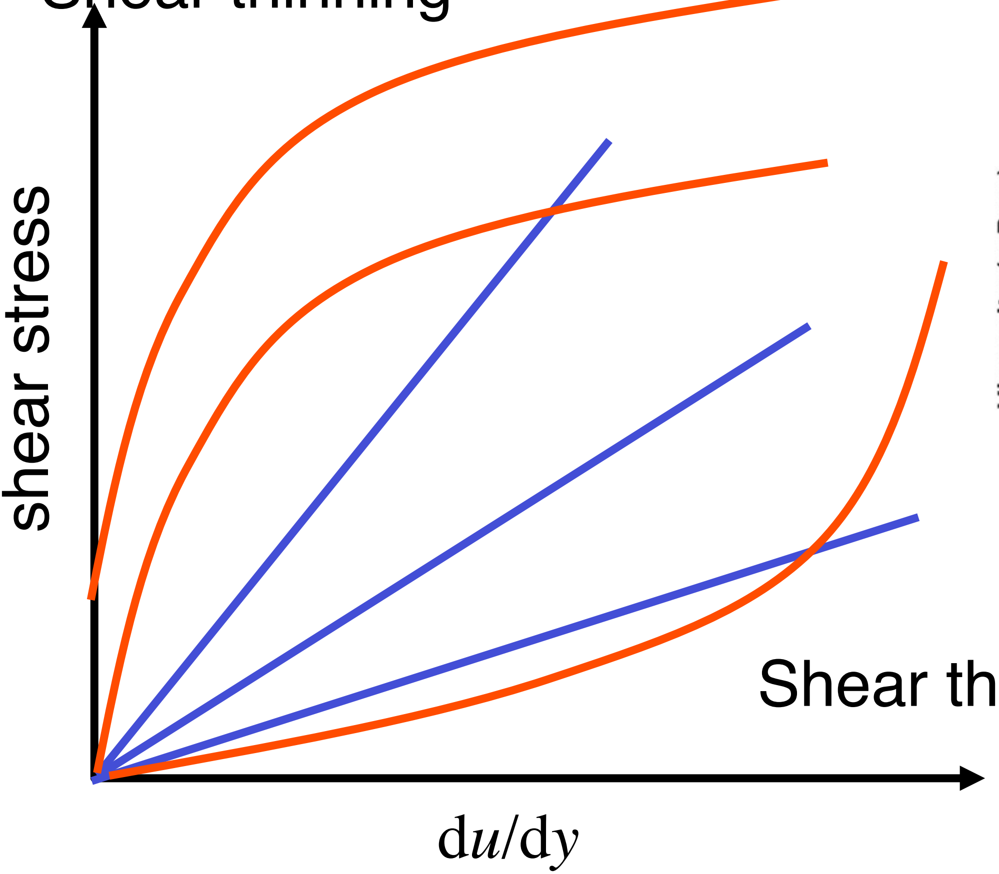
- temperature
- concentration of dissolved solutes
- shear rate (rate of strain)

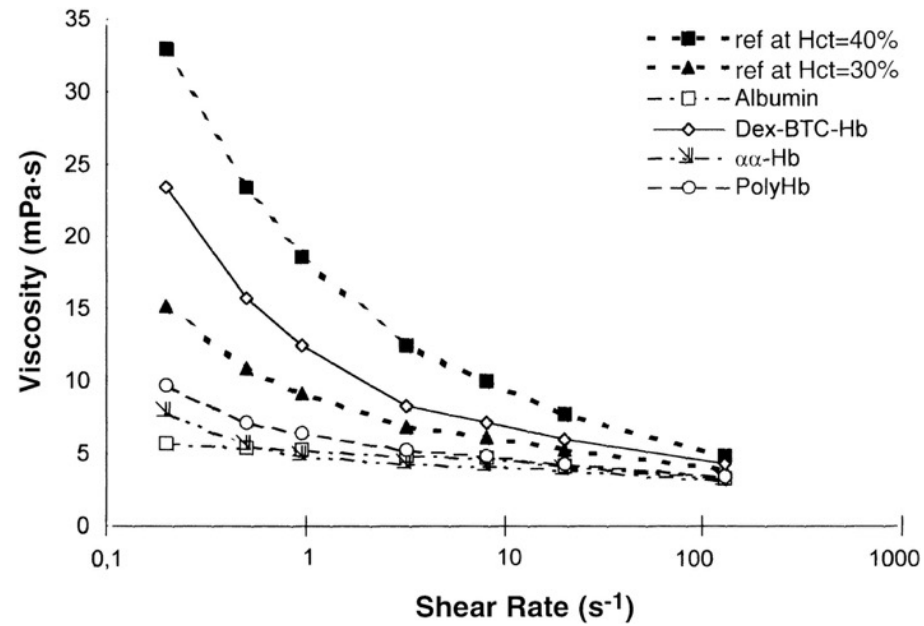
Determinants of viscosity: shear rate

Newtonian fluids

non-Newtonian fluids Blood

Shear thinning





Shear thickening

Cardiovascular and hemorheological effects of three modified human hemoglobin solutions in hemodiluted rabbits

Alexis Caron, Patrick Menu, Beatrice Faivre-Fiorina, Pierre Labrude, Abdu I. Alayash, Claude Vigneron
Journal of Applied Physiology Published 1 February 1999 Vol. 86 no. 2, 541-548 DOI:

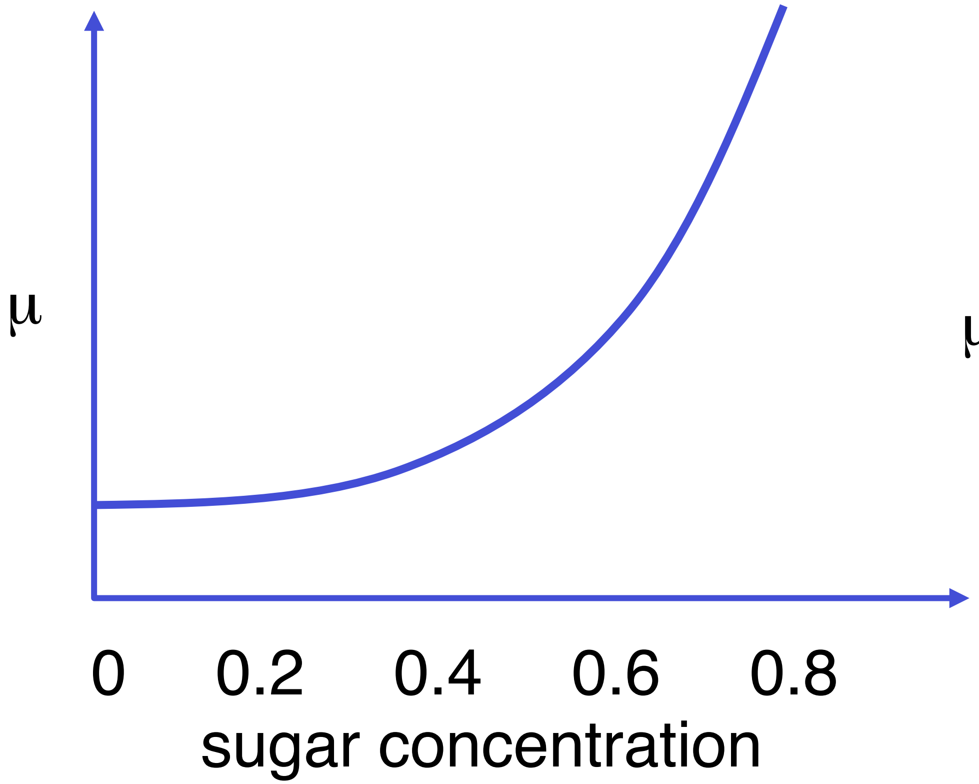
Determinants of viscosity: temperature

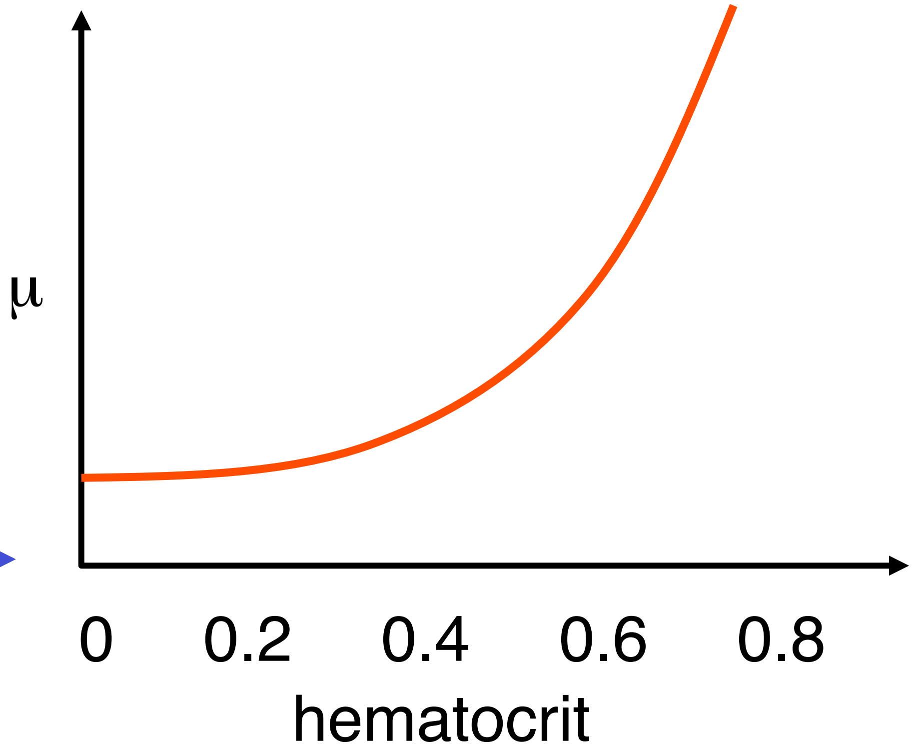
Temperature: a huge latitudinal gradient
Oceanic West coast 6 - 26
Oceanic East coast 2 - 32
Freshwater - 0 - 80 (Atlantic waters)

	0	20	40
Water kg/ m s	0.0018	0.001	0.0006
Air g/ m s	0.0017 g/ m s	0.0018	0.0019

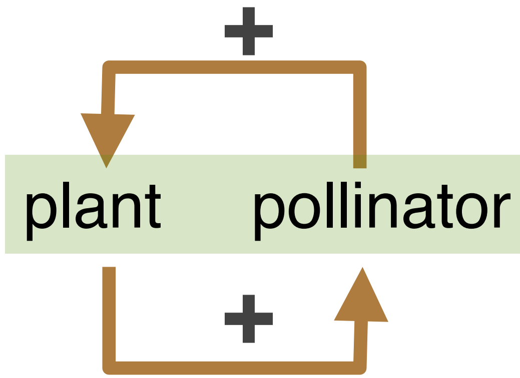
Determinants of viscosity: concentration

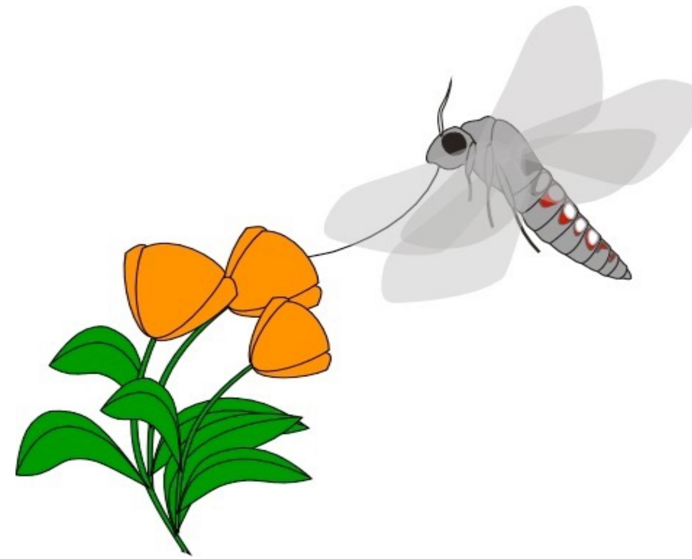
Increases exponentially with concentration of dissolved or suspended solutes.



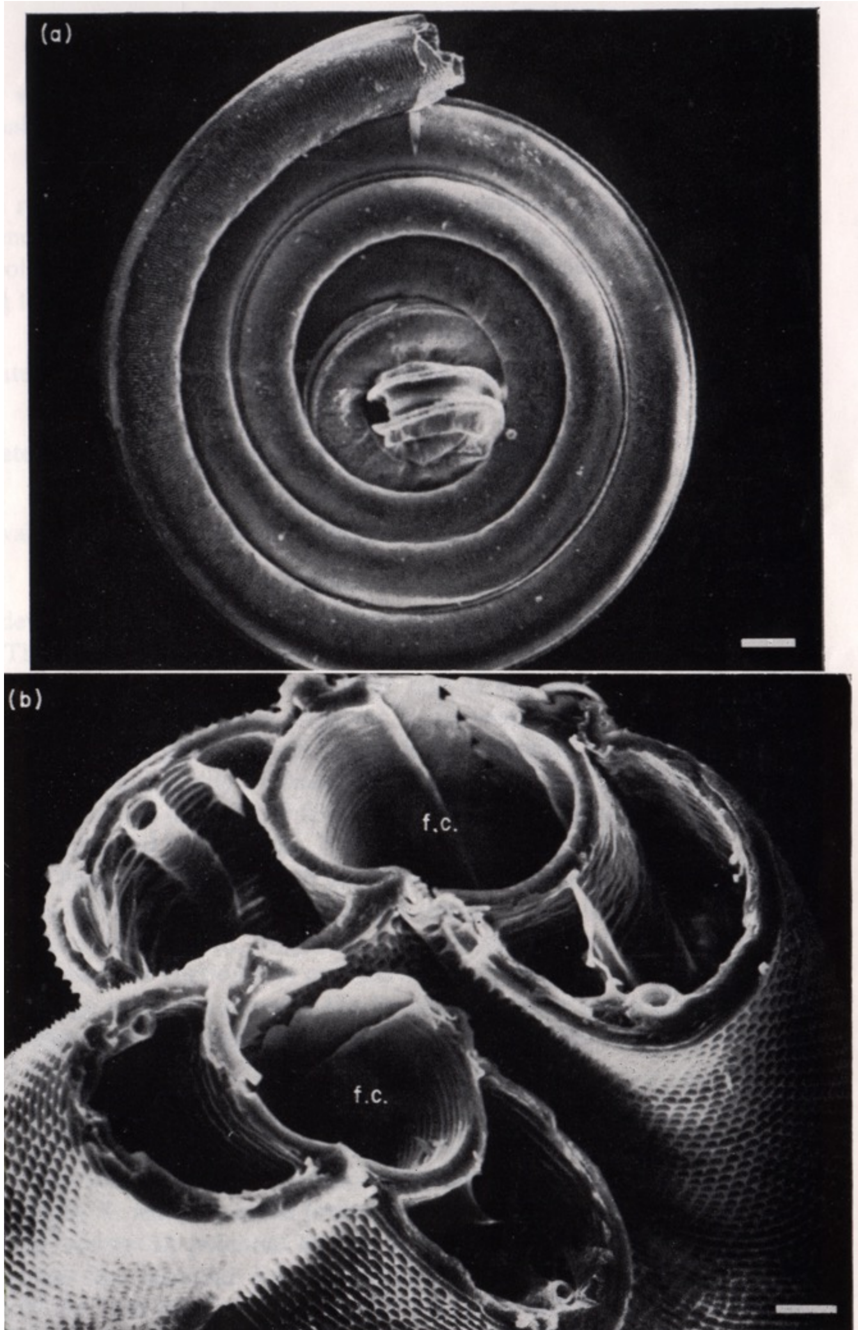


A coevolutionary process:
Why do plants produce dilute nectars?

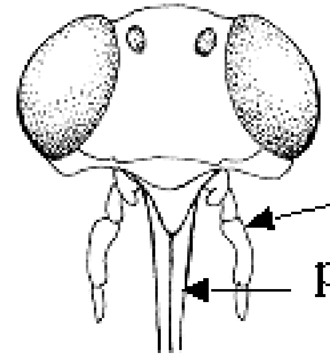


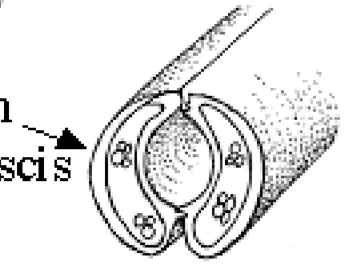


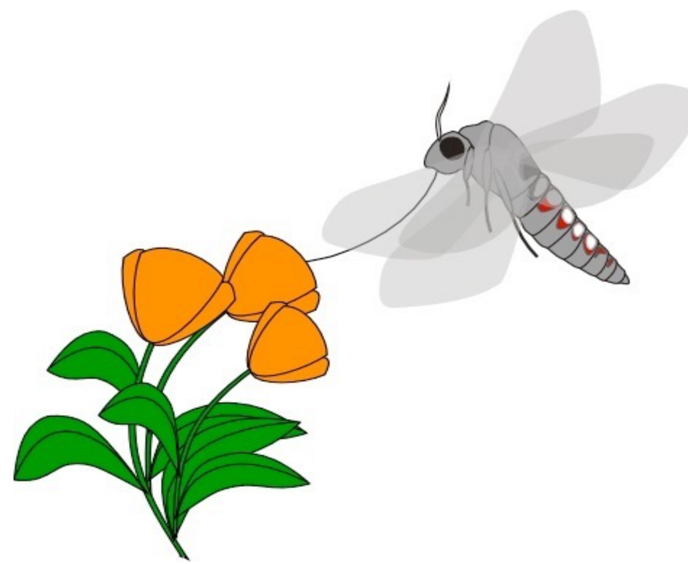
Butterfly and moth pollinated flowers typically produce dilute nectars: ~20% sugar concentration.



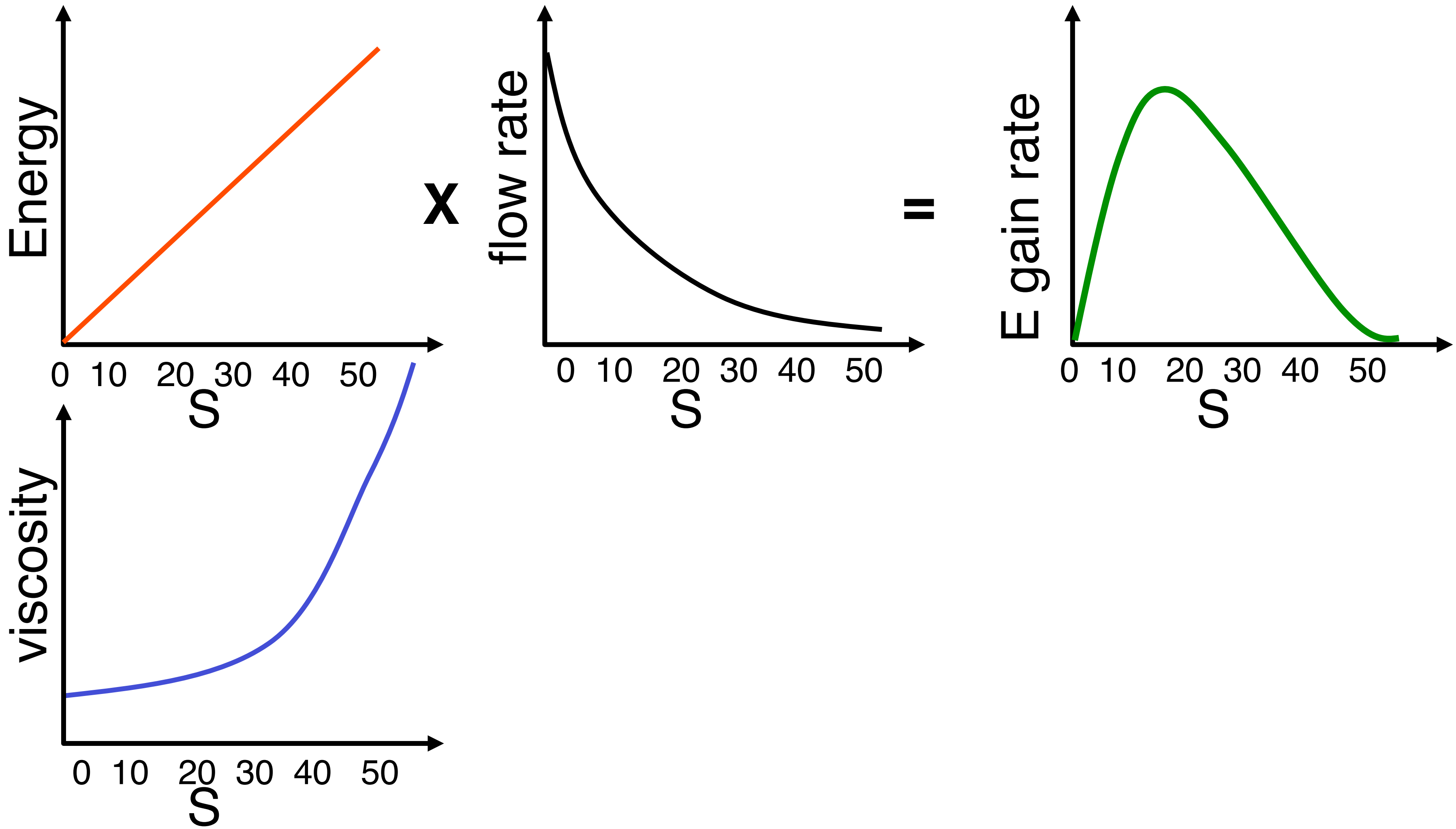
Butterfly mouth parts







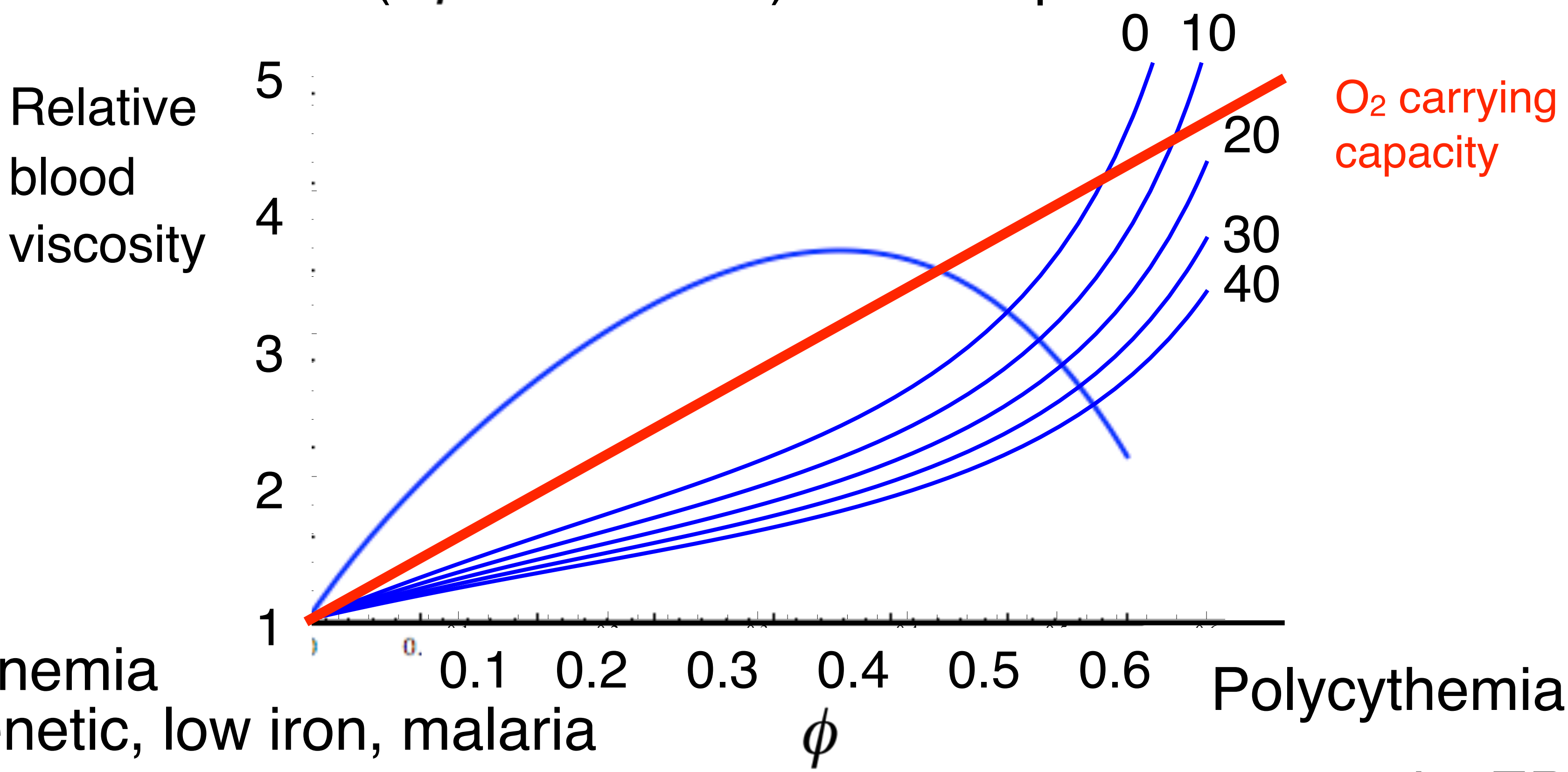
Low sucrose concentration [S] in butterfly pollinated flowers (20%)



Determinants of viscosity: blood is a suspension of elastic red blood cells (each about 7 um in diameter) in plasma. The normal concentration of red blood cells is 0.4 (40% by volume)

(1) why is our blood hematocrit at 0.4?
(2) is blood doping advantageous or detrimental?

Blood viscosity depends non-linearly on red blood cell concentration (ϕ hematocrit) and Temperature



Anemia
genetic, low iron, malaria

Polycythemia

genetic, EPO, blood doping, dehydration

Blood viscosity depends non-linearly on red blood cell concentration (ϕ hematocrit) and Temperature

Relative blood viscosity $\frac{K^2}{\mu_p}$

5

$$\sqrt{\tau} = K\sqrt{\frac{du}{dr}} + \sqrt{C}$$

4

3

$$K^2 = \frac{\mu_p}{1 - \alpha\phi}$$

2

$$\alpha = 0.07\exp[2.49\phi + 1107\exp[-1.65\phi]/T_K]$$

1

0.1 0.2 0.3 0.4 0.5 0.6

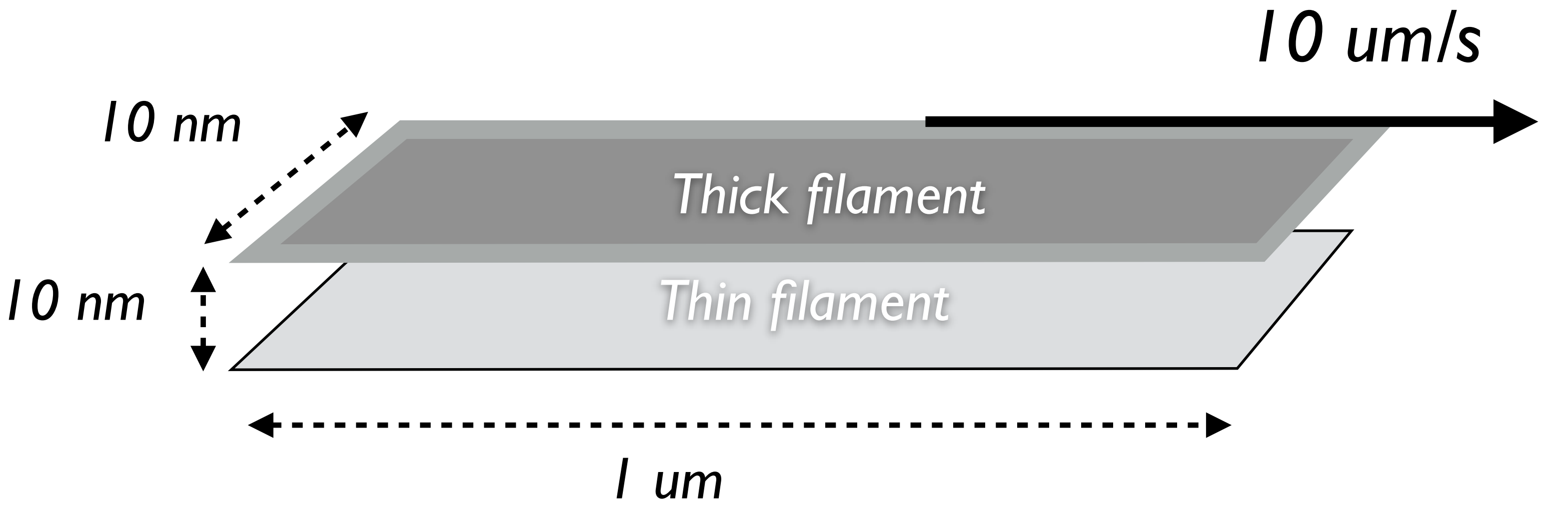
ϕ

Anemia

Polycythemia

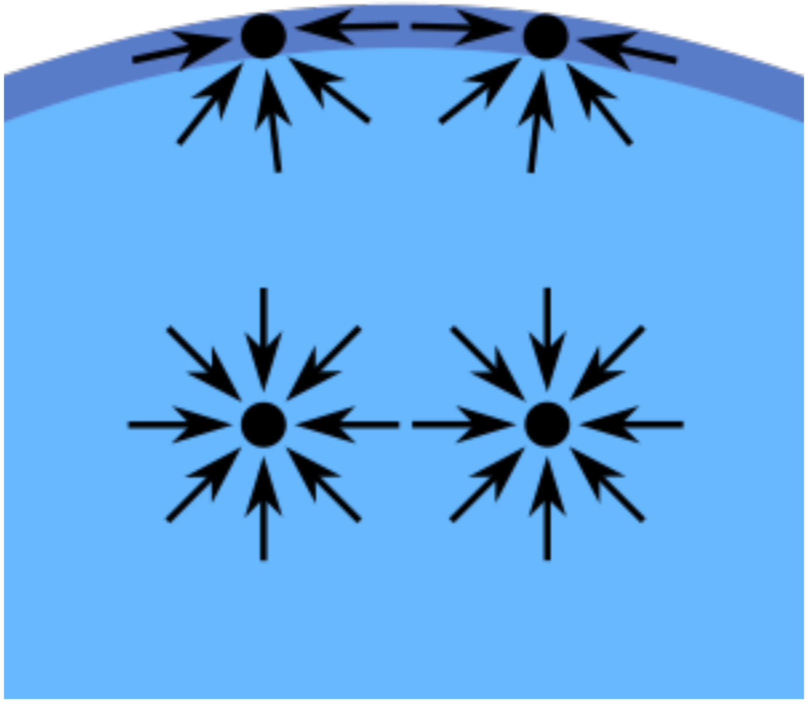
genetic, low iron, malaria

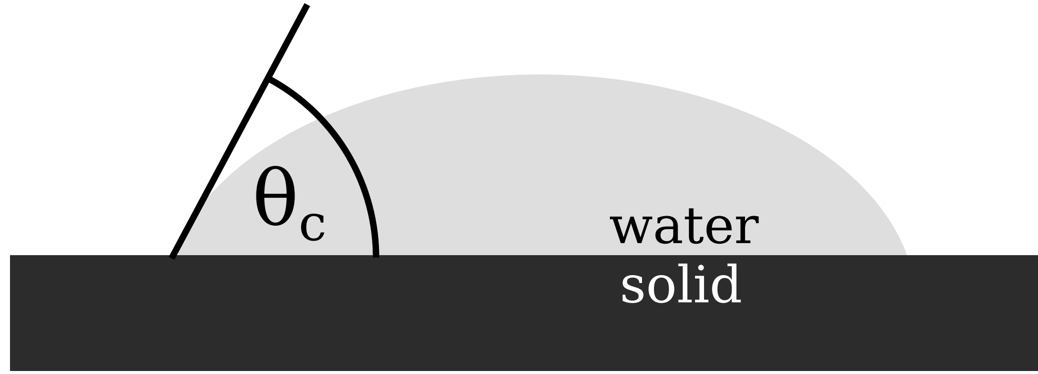
genetic, EPO, blood doping, dehydration

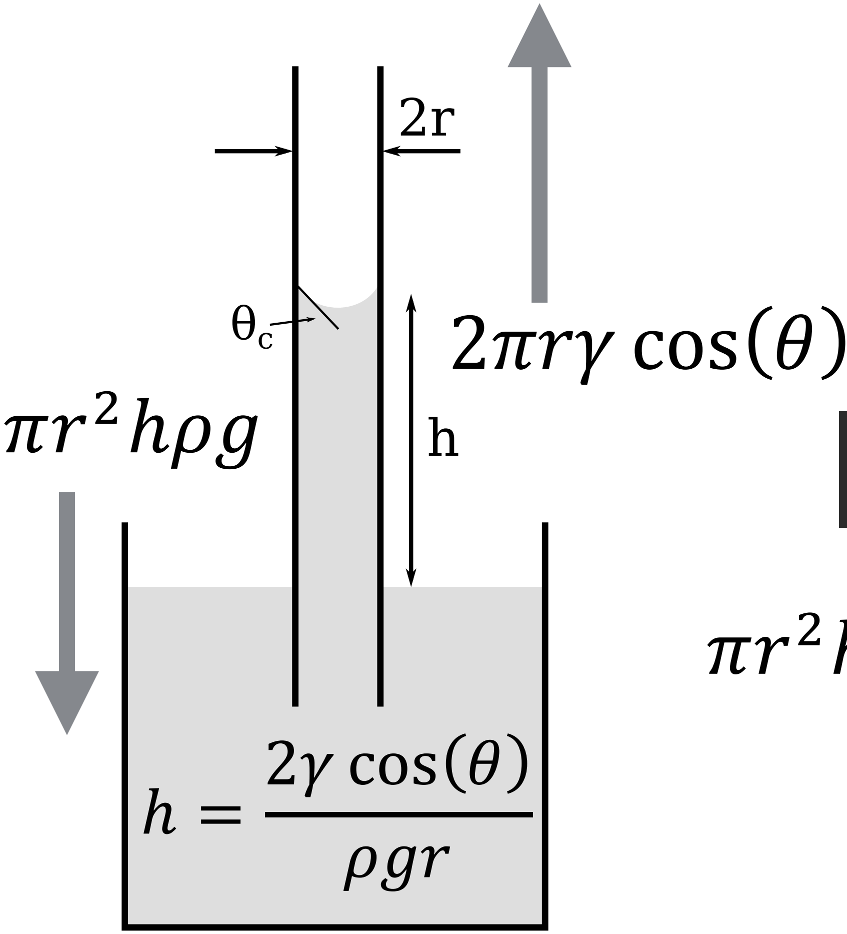


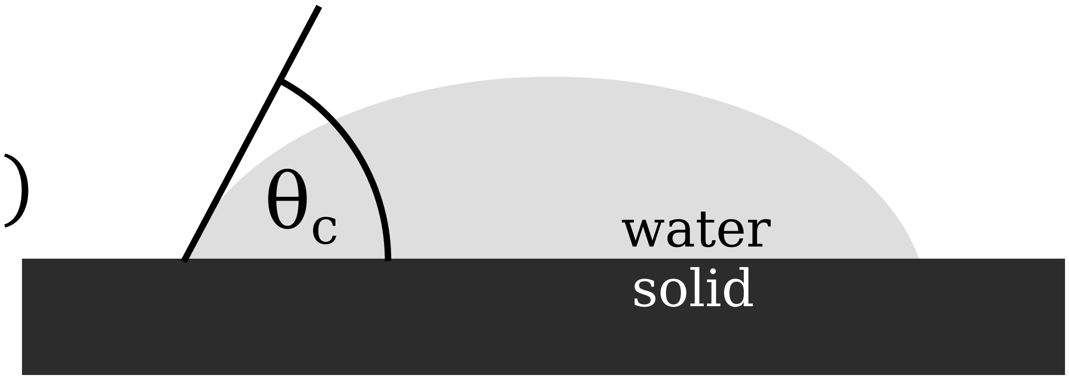
What is the velocity gradient?
What is the shear rate (strain rate)?

Definition: A fluid (gas or liquid) deforms continuously under an applied stress.




θ_c
water
solid





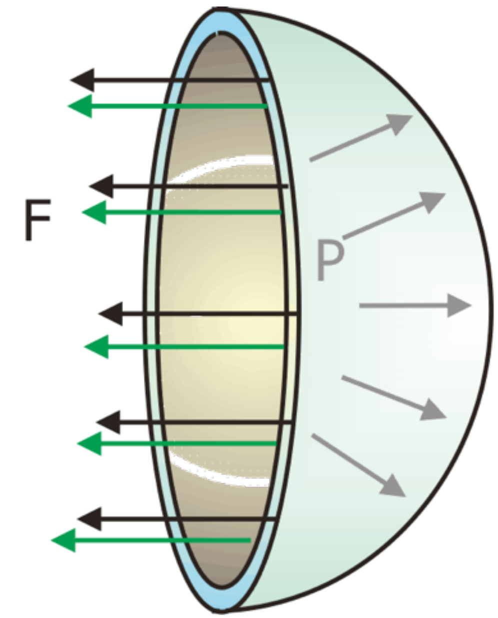
$$\pi r^2 h\rho g = 2\pi r\gamma\cos(\theta)$$

water
0.0728 N/m

For one surface (like a baloon)

$$F_{pressure} = \Delta P \pi r^2 = T 2 \pi r$$

Exercise: For a bubble with an inner and outer surface, what is the correct relationship between above?



Exercise 2 What will happen when a hole appears between:

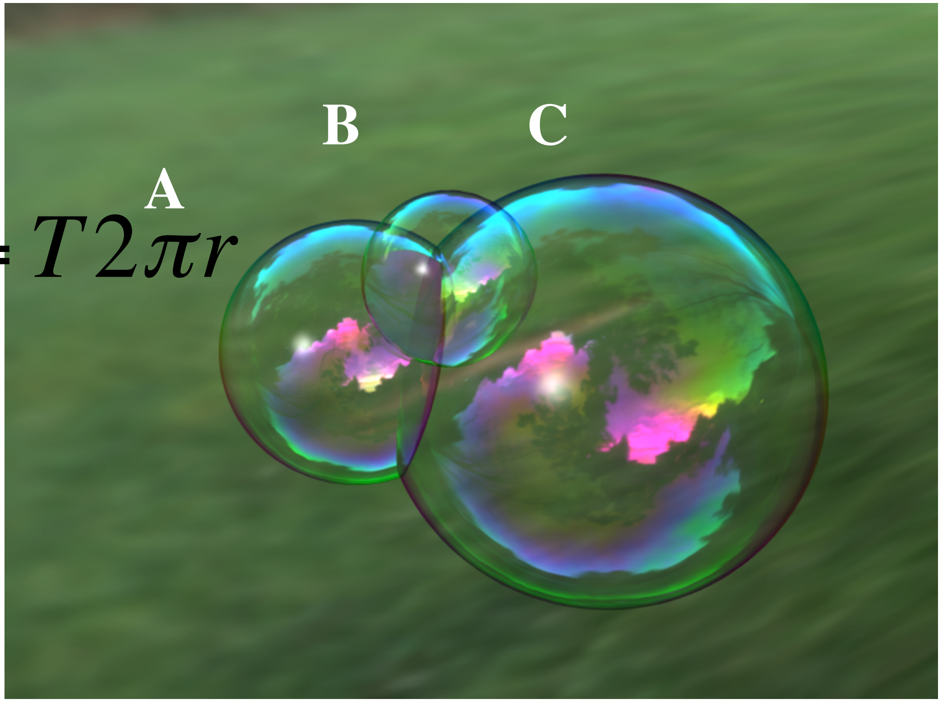
A and B

B and C

A and C

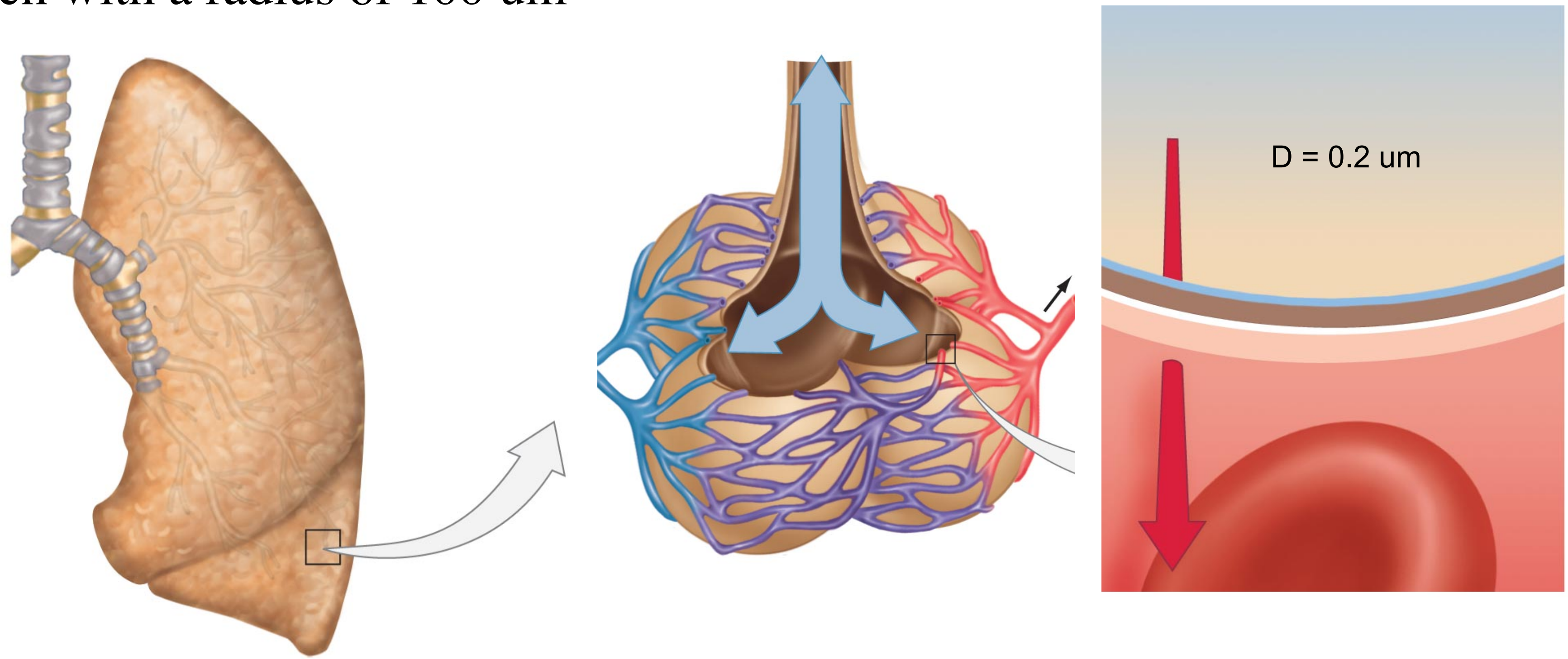
and .. why?

$$F_{pressure} = \Delta P \pi r^2 = T 2 \pi r$$



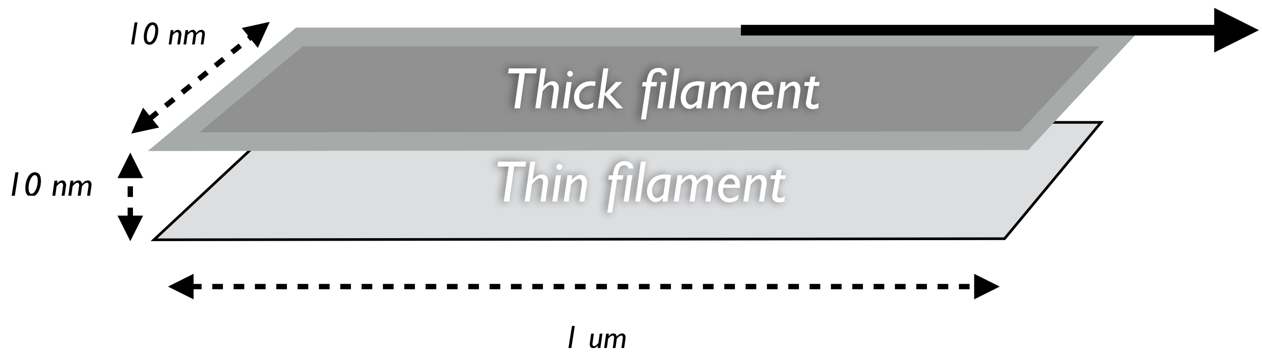
About 0.5 billion alveoli in lungs
each lined with fluid
each with a radius of 100 um

Exercise: Is the correct relationship *Pr = 2T* or *Pr = 4T*? Why?



With a surface tension coefficient of 0.0728 N/m (J/m^2)
what is the total pressure in each alveolus maintaining
that thin liquid film?
Ans 1456 Pa.
and half a billion of those too!

What is the velocity gradient?
What is the shear rate (strain rate)?



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