The University of British Columbia

BIOL/PHYS 438 Assignment # 2: MUSCLES, TENDONS & GASES

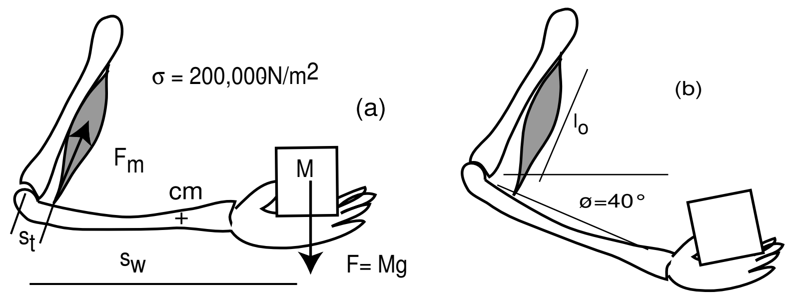
Tue. 23 Jan. 2007 — finish by Tue. 06 Feb.

Please hand in one assignment per group and list the names & Email addresses of all group members at the top of each sheet. In general, *if you think some necessary information is missing, make a reasonable assumption.* But always *write down* what that assumption is. Always estimate your *uncertainty* in any measured quantity, and don't forget to specify all *units*.

If possible, justify your input. For original comments you may score bonus points!

1. ARMSTRONG:

Consider a human biceps as shown below.



(*a*) Measure your biceps length ℓ_0 and the distance s_w. Estimate the distance s_t (explain how you do this). Determine your muscle contraction $\Delta\ell$ from similar triangles $\Delta h/s_w = \Delta\ell/s_t$ when moving the hand between positions (a) and (b). Does the maximum contraction agree with the often quoted value $\Delta\ell/\ell_0 = 10\%$?[1] Determine the average cross sectional area and length of your biceps muscle to find its volume $V_{\rm bic}$ and mass $M_{\rm bic} = \rho V_{\rm bic}$. What value should you use for the muscle density ρ?

(*b*) Find a heavy weight, say M = 5-10 kg, lift it as quickly as you can $n = 10$ times,[2] and record the time $\Delta t_{10} = 10\Delta t$ for these 10 cycles. Estimate the average time Δt_c that the muscle spent *contracting* in each cycle, determine your normalized muscle contraction speed $V = \Delta\ell/(\ell \times \Delta t_c)$, and compare it to the normalized maximum power speed $V_{mp} \approx 0.3V_0$ [s^{-1}], where V_0 is the intrinsic muscle velocity for humans.[3] Comment on the result.

Determine the power needed to raise the weight: $P = Mg\Delta h/\Delta t$. Estimate the mass m_a of your forearm and the approximate position of its center of mass (cm), so that you can get estimates of the force F_a and power P_a needed to move the forearm. Add the forces $F_m = F + F_a$ and the powers $P_m = P + P_a$ and give estimates of the specific muscle force $f = F_m/A$ and the specific muscle power of your biceps $p = P_m/m_a$.

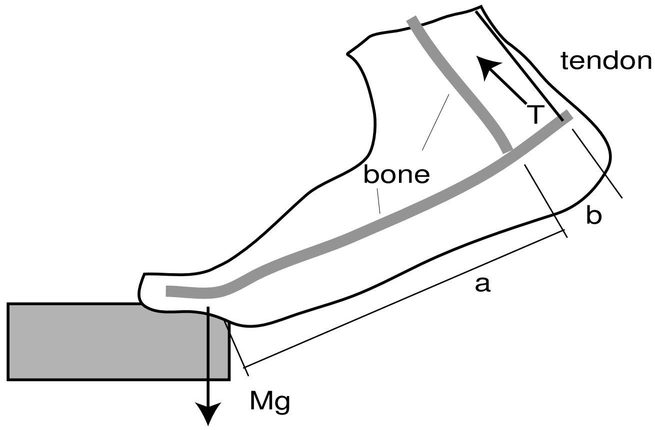
Make a table of $\Delta\ell/\ell_0$, m_a, contraction frequency $\nu = n/\Delta t_{10}$, V/V_0, f and p for all team members.

[1] See section **3.2 Muscles and Tendons** in the textbook.

[2] You should choose a weight heavy enough that "as fast as you can" does not have you actually *pulling the weight back down* on each swing, otherwise you will be doing extra work that this calculation does not account for. (Imagine doing this exercise in free fall and you will understand.) But don't lift such a heavy weight that it causes injury!

[3] See section **3.2.4 Muscle Efficiency**.

2. TENDON FORCES:



(a) Calculate the tension T in the Achilles tendon of each member of your group when he or she stands on the toes of one foot on a staircase, as shown above. For that you will have to know the person's body mass M and the relevant dimensions of their foot.

(b) Measure the radius r of each person's Achilles tendon and determine the corresponding specific stress $\tau = T/(\pi r^2)$.

(c) Make a table of M, T and τ for all team members. Email this information (in plain text, please!) to Alex and he will make a compound table of this data for the whole class.

3. BREEZING IN WHITEHORSE: On a fine winter morning in the Klondike the air is a balmy $T_0 = 30°$C below the freezing point, and the pressure is at $p = 1.03$ bar $= 1.03 \times 10^5$ N/m^2. Robert Rednose breathes deeply before descending into his gold mine, and takes in air at an average volume flow rate $\Phi = A \times u = 6.0$ liter/min. (u is defined below). The air has to pass through his nostrils, which have a total opening area of $A = 2.8$ cm^2. The air warms up to the body temperature $T_B = +36°$C inside the lung.

Air is a (mostly diatomic) molecular gas with specific heat $C_p = (7/2)R$, where $R = 8.31$ J/mole·°K is the gas constant. Recall the Ideal Gas Law $pV = nRT$, where the pressure p is in N/m^2, the volume V is in m^3, n is the number of moles in the volume V and the temperature T is always in °K. Differentiate the caloric energy equation, $\Delta Q = nC_p\Delta T$, to get the heat flow rate that must be provided by the lung to maintain 36°C.

(a) How many moles are in one liter at this temperature and pressure? How many moles per second does he inhale?

(b) How much heat power [Watts] does Robert lose by warming up the air?

(c) What is the average intake velocity u at which the air streams through his nostrils?

(d) Is the flow laminar ($Re \lesssim 2300$) or turbulent ($Re \gtrsim 2300$)?[4]

(e) Measure the open area A of your own nose and provide this data along with the body mass for each individual. Plot the area A as an allometric relation $A = aM^\alpha$ on a log − log graph for the members of your group. What is the scaling exponent α for your data? What exponent do you expect? Why?

[4]Here $Re = uR/\nu$, where u = flow velocity, R = typical radius of flow channel and ν = kinematic viscosity of air — see Eq. (**4.12**) and the text between Figs. **4.8** and **4.10**.