The University of British Columbia

BIOL/PHYS 438 Assignment # 1: METABOLISM

Tue. 09 Jan. 2007 — finish by Tue. 23 Jan.

The first part of this assignment is not for credit, but you'll probably be glad if you do it anyway! We sure will.

- **GET CONNECTED:** Go to the 438 Homepage at `http://musr.physics.ubc.ca/p438/` and
  - **Browse**. Make sure you know what's there, how to get to it and what it's good for (if anything). Email `jess@physics.ubc.ca` if you have any questions.
  - Make sure you can **log in** on that site and that there is *one and only one* entry for you in the 438 People Database. Your User ID and your initial password are both set to *your student number*. You may wish to change your password.[1] Your Profile in the 438 People Database has fields for all sorts of information about you, most of which are blank. You may want to Update your Profile, either to add/correct said information or to alter your privacy setting (at the bottom of the Update form).
  - Repeat the steps above for the 438 *WebCT* site[2] (to which there is a link on the 438 Homepage). This site is handy for certain things like Discussions, tentative Marks and your own personal 438 Homepage (if you'd like one); we may also use it for other things like chat or whiteboard work; if you have an idea for more creative uses of *WebCT*, please tell us about it.
  - **Send us an Email** containing a brief description of who you are, what talents and skills you bring to the 438 community, and what you hope to get out of the course. Please send this to `jess@physics.ubc.ca` *and* `jergold@zoology.ubc.ca` *and* `aweber@physics.ubc.ca` *from your own preferred Email address*, so we will all know how to contact each other in emergencies.

For the rest of the Assignment (and for all subsequent Assignments), *join a group of 3-5 students*. 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.

1. STAIRCASE OLYMPICS:

(*a*) Determine the mechanical power output[3] $P_{\rm walk}$ for each team member[4] walking up four flights of stairs (four floors) in the Hebb building. The height of one "floor" in the Hebb staircase is $h = 7.28$ m; if you do the exercise anywhere else you must measure h. By the definition of the mechanical efficiency $\eta \equiv P/\Gamma$, we have $P_{\rm walk} = \eta_{\rm walk} \times \Gamma_{\rm walk}$ where $\Gamma_{\rm walk} = b_{\rm walk} \times \Gamma_0$ is the metabolic rate while walking up the stairs and $b_{\rm walk}$ is the corresponding metabolic activity factor. Calculate $\Gamma_{\rm walk}$ and $b_{\rm walk}$ for each team member. What value should you take for η? Discuss this choice and comment upon its validity in your written report.

(*b*) Estimate your uncertainty in this measurement.[5] The largest possible value, $P_{\max}$, is found by combining the largest likely value of your body mass, M_+,[6] and the shortest possible time Δt_-. Similarly

[1] Note that this ID/password combination is completely independent of any others you may already have memorized! Sorry about that, but ITservices still hasn't provided the third party CWL authentication they promised years ago.

[2] You must use your CWL (Campus-Wide Login) username/password to log in to any *WebCT* course.

[3] Note that we are focusing only on "useful work" (raising your mass against gravity); the work done by individual muscles moving body parts back and forth in walking along a *level* path is ignored here (*i.e.* it is included in $\Gamma_{\rm walk}$ but not in $P_{\rm walk}$).

[4] Please do not attempt this exercise yourself if you are not sure you can perform the climb without excessive exertion or health risk. Each group should, however, have at least two climbing members.

[5] This is often referred to as an "error estimate" but there is no negative connotation in estimating your uncertainty; it is not an "error" but merely an honest observation. Reporting measurements *without* any uncertainty is, by contrast, fundamentally *dis*honest!

[6] You probably know your "bare" weight from the Doctor's office, but did you have a heavy wallet in your pocket then?

combine the lowest likely body mass M_- and the longest likely time Δt_+ to find a value for P_{min}. A good estimate of the uncertainty in your experimental result is thus $\delta P = (P_{\text{max}} - P_{\text{min}})/2$. Express your answer for the power P_{walk} in the form $P \pm \delta P$ W. (Always include *units*.)

(*c*) Determine $P \pm \delta P$ for each one of your team members when running up the stairs.[7]

(*d*) Estimate the mass of the muscles M_{musc} used for running up the stairs and give the power to mass ratio $X_{\text{run}} = P_{\text{run}}/M_{\text{musc}}$ of these muscles.[8] Muscle mass (M_{musc}) = muscle volume (V_{musc}) times muscle density (ρ). Muscles have about the same density as water.

(*e*) Make a *table* including all your data showing `Name`, M, Δt_{walk}, P_{walk}, Γ_{walk}, Δt_{run}, P_{run}, Γ_{run}, Γ_0, V_{musc} and X_{run}, including the *uncertainty* in each. *Explain your most significant sources of uncertainty.*

(*f*) Make a log-log graph for each of P_{walk}, P_{run}, Γ_{walk}, Γ_{run}, Γ_0 and X_{run} as functions of body mass M.

The TA will make a compound table for the whole class to get statistical correlations.

2. SO SWEET SO MEAN: A hummingbird weighing $M = 3.9$ g visits 1000 flowers daily and thereby collects nectar with an energy content of $\Delta H = 7 - 12$ kcal [see R. Conniff 2000][9]

(*a*) Take an average value of $\Delta H = 9 \pm 2$ kcal. What is the sugar and honey content of the nectar? (Honey has about 14/15 of the heat of combustion of sugar.)

(*b*) Determine the metabolic rate Γ of the little bird, and estimate its mechanical power output P. Assuming the metabolic rate function $\Gamma_0 = a\ M^{3/4}$ is applicable, determine the constant a in that rate function.

(*c*) Compare your calculated value of a with the constant $a_0 \approx 4$ of the mouse to elephant curve [Eq. (1.5) in the textbook] and determine the ratio $r = a/a_0$. Should this ratio be equal to the activity factor b calculated for the staircase run?

(*d*) What problems can you foresee for such a high metabolic rate?

(*e*) Calculate the specific metabolic rate $\gamma \equiv \Gamma/M$ for the hummingbird and for a 5-ton elephant. Which animal makes better use of the energy resources of the environment?

3. HOT DEFENCES: Giant hornets like to eat bee larvae and honey. They are so strong that they can just invade a beehive and kill the guards at the entrance and get at their favourite food. A certain strain of Japanese honey bees has found a thermodynamic defence. They can tolerate a temperature of 47.2°C (118°F). The hornets however can only stand 46.1°C (115°F). The bees have learned to raise their body temperature to 47.2° (117°F): they humm while contracting and relaxing their flight muscles, and only generate heat without producing external mechanical work ... and thereby steam the hornets in their own juice. Take a specific muscle power of $p = P/M = 150$ W/kg. The specific heat of tissue is close to that of water. Assume that the bees normally have a body temperature of 43°C and that 10% of the body weight of a bee is muscle.

(*a*) How much heat energy must be generated by each bee to reach the killing temperature?

(*b*) What is the heating power of each bee?

(*c*) How quickly do the bees reach the killing temperature?

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[7] See the *caveat* for the first question.

[8] A good automobile engine generates about 1 kW/kg.

[9] R. Conniff, "So sweet, so mean" *Smithonian*, Sept. 2000, pp. 72-82.