Order-of-Magnitude Physics – Lab 6

Guidelines:

- Break up into groups of 1, 2, or 3 people (no more than 3 please)
- You can switch scribes between various parts.

Problem 1. Pedal Power

You are pedalling your bicycle and generating 250 W of mechanical power.

(a) If there were no heat flow out of your leg muscles, **how long (in s) would it take for the temperature inside your legs to rise by 1 K** (onset of fever / protein denaturation)?

(b) If the inner temperature of your legs did rise by 1 K, **what fraction of the heat generated could be carried by static thermal conduction** in the leg tissue?

(c) In reality, the excess heat is carried from the leg interior to the skin not by conduction but by blood. Estimate the **volume of blood flow (in $\mathbf{cm^3\ s^{-1}}$)** required to transport enough heat to limit your leg temperature rise to 1 K. Convert into **heartbeats per minute.**

(d) Say this activity is powered by *aerobic* respiration. Estimate the **mass of oxygen per time (g $\mathbf{s^{-1}}$)** that must be carried to the muscles to sustain the exercise aerobically. Convert into **breaths per minute**.

(e) Use your answers in (c) and (d) to estimate the mass of oxygen carried per unit volume of blood. Oxygen is carried by red blood cells. Half of your blood volume is occupied by red blood cells, and one third of every red blood cell is composed of hemoglobin. One molecule of oxygenated hemoglobin carries 1 O_2 molecule. Deduce the **molecular weight of hemoglobin (in amu's)**.

(f) On *anaerobic* respiration, enough energy is stored in adenosine triphosphate / phosphocreatine (ATP/PCr) to produce 750 Watts of mechanical power for ∼10 seconds without your heart having to pump faster. **Would there be a point to storing more energy?**

Problem 2. The Longest Canoe

The "hull speed" of a ship increases as the square root of its waterline length L. The hull speed is often used as an estimate for the maximum speed of the ship; at ship speeds greater than the hull speed, the power requirements required to fight wave drag become exorbitant.

This line of reasoning suggests that to go faster, one should build longer ships. Yet the fastest canoes on Earth — powered by humans — do not exceed a certain length. **Estimate this maximum length (in m).**

Pages 225–226 in the Course Reader cover wave drag. But not all of the drag is wave drag.

Problem 3. Resonant Tubes

For this problem, please try to keep track of factors of order unity.

Consider a tube of length L that is closed on one end and open on the other.

(a) **Write down the wavelength λ of the fundamental sound wave (in units of L)** supported by the tube. This fundamental mode is a *standing wave*: one whose nodes and antinodes are fixed in space and time.

Ask whether the closed end represents a pressure node or antinode. Ask the same question for the open end.

Hint: The wavelength of the fundamental mode is allowed to be somewhat greater than L.

(b) **Estimate the fundamental frequency ν (in Hz) of your ear canal (a.k.a. the auditory canal).** Compare your answer to pages 238 and 239 of the Course Reader.

(c) Now consider shallow water waves in the Bay of Fundy, whose tidal range is the largest in the world (extending up to 51 feet).

The fundamental mode of the Bay is resonant with the Moon's fundamental tidal forcing frequency. The total length of the Bay is $L = 300$ km. **Deduce the Bay's depth (in m).**