IB 135 MECHANICS OF ORGANISMS
Midterm Exam #1, Fall 2007

Name: ________________________

Student ID #: ___________________________

Section #: _________ Section day and time: ___________

PAGE	POINTS	SCORE
2		
3		
4		
5		
6		
7		
8		
TOTAL	100	

READ INSTRUCTIONS CAREFULLY!!!

1. Write legibly. If we can't read what you've written, no points.
2. The appendix at the end of the exam contains equations, some of which may help you figure out your answers to some of the questions.
3. If you use diagrams or graphs, they MUST BE LABELED. IF THEY ARE NOT LABELED, NO POINTS.
4. There are 100 points on this exam. Budget your time accordingly.
5. All values that have dimensions should be LABELLED WITH THEIR UNITS. This exam is in S.I. units.
6. **Put your name on every page**. DO IT NOW!!! We'll take a point off if your name is missing from any of your question pages.
7. Confine answers to the space provided for each.

There are 6 questions and **6 pages** (including this one).
MAKE SURE THAT YOU HAVE THEM ALL.

_____1. a) Is the blood pressure in the head of giraffe standing upright higher or lower than the blood pressure in its aorta? (2 points)
lower

b) What happens to the blood pressure in the giraffe's head when it drinks water from a pond? Explain your answer. (10 points)
The blood pressure in the head of the giraffe **increases** above the pressure at the height of its heart as it lowers its head down to ground-level to drink from a pond. *(2 points)*

This occurs because, according to Bernoulli's law, the sum of the kinetic energy per volume of blood plus the pressure plus the gravitational potential energy per volume is a constant. Therefore, if the gravitational potential energy per volume of blood goes down in the giraffe's head when it drinks from a pond, then the pressure goes up. *(8 points)*
(Note: Explaining this using the equation is correct as well, BUT if the symbols or terms in the equation are not defined or explained, then 6 points. Simply writing the equation with ***no*** *explanation - 4 points.)*
(Note: Correctly explaining this in terms of the weight of the blood, as the section of the assigned reading in the handout from Schmidt-Nielson's book did, is also worth 8 points.)

(This pressure can be very high in a giraffe because it is so tall. The heart has to generate a very high pressure to pump the blood up into the head of an upright giraffe, and the head of an adult giraffe can be as much as 2 m below the heart when it drinks, leading to a very large increase in pressure. *1 bonus point for this additional information, but no score can be greater that a total of 10 points for this question*)

partial credit for the following:

-talking about a change in potential energy without further explanation (potential energy is $p + \rho gh$, so the full answer is that gravitational potential energy is being converted into pressure potential energy, according to Bernoulli's law) *(4 pts)*

-talking about the height of the column of blood, or the change in the height of the column of blood, without explicitly explaining what this change in height does (i.e. either talking about the weight of that column of blood, or else that the change in height trades off with pressure, according to Bernoulli's law) *(4 pts)*

Note: Providing a correct answer, but adding additional irrelevant <u>incorrect</u> information *(-1 or -2 points for incorrect information)*
Note: Adding irrelevant information that <u>is</u> correct (i.e. something correct but not a part of the answer) *does <u>not</u>* result in losing points.

c) Name <u>one</u> of the features that a giraffe has that mitigates the problems that might otherwise occur due to the blood pressure in its head while drinking from a pond. (4 points) *full credit, 4 points, for any one of these:*

Giraffe's have one-way valves in the veins of their necks to impede backflow of venous blood into the head when their head when they are drinking from a pond. *(4 points)*

or

Giraffe's have a thick connective tissue sheath around their necks that acts like a support stocking to help prevent the blood vessels of the neck from swelling too much when the bood pressure is very high when they are drinking from a pond.

or

rete mirable *(4 points*),

or a functional explanation of what the rete mirable is without naming it (a system of extensible blood vessels that can accomodate extra blood when the head is lowered) *(4 points*)

or

A connection between the carotid and the vertebral artery that drains off a portion of the blood before it gets to the head. *(4 points*)

partial credit :

1 point for valves in arteries (they do have valves in their arteries, but these do not help with the problem of having their head so far below the heart -- think about it!)

2 points for valves in the veins (rather than one-way valves),

NO CREDIT for valves that regulate the amount of blood being pumped (the valves that are relevant to this problem are the ones that limit blood backflow in the veins)

Note: If you said that splaying front legs to slightly decrease the height difference between head and heart, that showed that you were thinking about the issue correctly IF you also explained that this decreases the height difference between head & heart. (Note: A giraffe has to splay its legs apart simply to get it's head low enough to reach the pond, so leg splaying isn't really a special feature to protect the brain while the animal is drinking. Nonetheless, we did give you full credit if you explained how this might help the protect the head from the pressure increase during drinking.) *(4 points)*

Simply saying that a giraffe lowered its body: *no credit*

Page 2 (continued)

_____ 2. In 1950 Nobel laureate A.V. Hill predicted that small and large animals should attain the same maximum running velocity. Velocity (V) is the product of stride length (L_s) X stride frequency (F_s). [The fig shown on the next page represents actual data. Do not use that graph for questions a-c.]

a) If Hill assumed geometric similarity and stride length was directly proportional to leg length (L), then how should stride length (L_s) scale as a function of body weight (W)? $L_s \propto W^{b?}$
(2 points)

$L_s \propto L$ and $L \propto W^{0.33}$ therefore
$L_s \propto W^{0.33}$

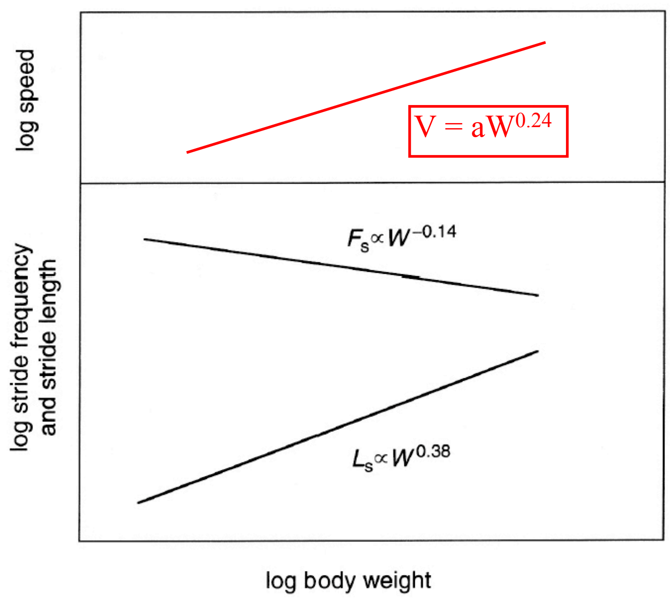
b) If Hill assumed stride frequency (F_s) was inversely proportional to leg length (L), then how should stride frequency (F_s) scale as a function of body weight (W)? $F_s \propto W^{b?}$ (2 points)

$F_s \propto 1/L$ and $L \propto W^{0.33}$ therefore
$F_s \propto 1/W^{0.33}$
$F_s \propto 1/W^{0.33}$
$F_s \propto W^{-0.33}$

c) Given the scaling of stride length and frequency, was Hill's prediction correct on the scaling of velocity? Why or why not? (4 points)

$L_s \propto W^{0.33}$
$F_s \propto W^{-0.33}$
$V = L_s * F_s$
$V = W^{0.33} * W^{-0.33}$
$V = W^{0.00}$
Yes. He was correct. Velocity should be independent of weight.

(question #2, continued)
Regression lines based on the stride length and speed of many mammals is shown in the figure. [The fig shown below represents actual data. Use for questions d-h.]



d) Does stride length scale with geometric similarity? (2 points)

Close. Need statistics. $L_s \propto W^{0.38}$ *(2 points)*

or
yes *(2 points)*

or
Also accepted: no, ONLY IF you explained that 0.38 ≠ 0.33, because this showed you understood that geometric similarity meant the slope should be 0.33 *(2 points)*

e) Does stride frequency scale with as Hill assumed? (2 points)

No. $F_s \propto W^{-0.14}$

f) How does speed scale with body weight? (4 points)

$V = W^{0.38} * W^{-0.14}$
$V = W^{0.24}$

also accepted: describing that speed scales positively with weight, but to a lesser degree than leg length scaled with weight

g) Draw the regression line for log speed as a function of log body weight on the figure. Don't worry about getting the slope exactly right, just indicate whether or not it is zero, positive or negative. (2 points)

h) Was Nobel laureate A.V. Hill correct about the scaling of speed and size? (2 points)

No.

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Note: FOR QUESTION 2, WE TRIED TO NOT TAKE OFF POINTS FOR A GIVEN MISTAKE MORE THAN ONCE. SO IF YOU GAVE A WRONG ANSWER, AND THEN LATER GAVE ANOTHER WRONG ANSWER THAT WAS CORRECTLY REASONED BUT BASED OFF OF THE FIRST WRONG ANSWER, WE USUALLY CREDITED THE SECOND ANSWER AS CORRECT

_____ 4. You are employed after graduation for a film company that makes documentaries about science for television. Your job is to check over the scripts for the narrators for each film and correct any errors. PICK TWO (2) OF THE FOLLOWING SECTIONS OF SCRIPTS BELOW. For each section of a script that you pick, check the "correct" blank if you think the statement is completely correct. Check the "incorrect' blank if you think that the statement is completely **or partially** wrong. Then explain why you think that the statement is correct or is wrong. (12 points each; total of 24 points for this page)

ANSWER TWO OF THESE. If you answer more, we will only grade the first two.

a. "A beating cilium works just like the oar of a rowboat." correct: ____ incorrect: X ← (1 point)

Why?

(8 points for either) → A cilium operates at low Re (or low Reynolds number), whereas an an oar operates at high Re (or high Reynolds number).

or

→ Viscous forces dominate the water flow around a cilium, whereas inertial forces dominate the water flow around an oar

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(11 points for any one of these answers)

– The thrust generated by an oar depends on the drag force on the oar. Drag on an oar (at high Re) is proportional to velocity^2, whereas drag on a cilium (at low Re) is proportional to velocity

or

– An oar does its power stroke in the water, and its return stroke in the air. Since drag depends on the density of the fluid (at high Re) the positive thrust generated during the oar's power stroke is much greater than the negative thrust generated during the return stroke in air. In contrast, a cilium does both its power and return strokes in water.

or

– The drag on the oar (at high Re) depends on the density of the fluid, whereas the drag on the cilium (at low Re) depends on the viscosity of the fluid

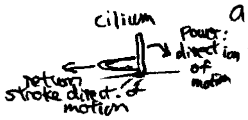
or

– When a boat is rowed by oars (at high Re), the boat coasts between power strokes. When a cell is propelled by cilia (at low Re), it does not coast

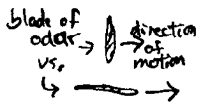
or

– A back-and-forth (reciprocal) motion by a flapping appendage (at low Re) produces no net motion, whereas a reciprocal motion of an oar can produce net motion in one direction if the power stroke is faster than the recovery stroke.

OR – they could answer "correct" ← (one point)



and explain how the drag coefficient of a cilium ⊥ to flow is greater than the drag ∥ to flow and explain how that can propel the cell



and then discuss rowing when you have the oar broadside to the flow relative to the oar during the power stroke (high drag) and is lower during the return stroke if the blade of the oar is oriented ∥ to the flow (lower drag) } 8 points

(note: 9 pts. total for this option because they missed the major point about Re!)

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ANSWER TWO OF THESE. If you answer more, we will only grade the first two.

b. "When the patient is ravaged by this dreaded disease, his windpipe becomes so inflamed that the diameter of the air passage is only half of what it was before he fell ill. The volume of air per time (V/t) that the sick patient can suck into his lungs when he is breathing at his maximum capacity is cut in half!" correct: ________ incorrect: __X__ Why? (1 point)

11 points for this much:

The volume flow rate through the windpipe is inversely proportional to the diameter of the pipe raised to the 4th power, so the V/t would be *much* lower than half of the V/t when the patient was well.

or

11 points if you did the calculation:

According to Poiseuille's equation,

$$\Delta P = \frac{Q l \mu}{r^4}$$

where: ΔP = pressure difference required to drive the air through the windpipe

Q = volume flow rate through the windpipe $= V/t$

l = pipe length

r = windpipe radius $= \frac{1}{2} d$ where d = pipe diameter

$$\therefore Q = V/t = \left(\frac{\Delta P}{l\mu}\right)\left(\frac{d}{2}\right)^4$$

Since the patient is breathing at maximum capacity, he is generating the highest ΔP he can. If we assume he can generate the same ΔP when he is ill as when he is well, then $\left(\frac{\Delta P}{l\mu}\right)$ is the same for the well patient and the sick patient

$$\therefore \frac{\left(\frac{V}{t}\right)_{sick}}{\left(\frac{V}{t}\right)_{well}} = \frac{\left(\frac{\Delta P}{l\mu}\right)\left(\frac{d}{4}\right)^4}{\left(\frac{\Delta P}{l\mu}\right)\left(\frac{d}{2}\right)^4}$$

← The diameter of the sick patient's windpipe is half of the diameter when he is well.

$$\frac{(V/t)_{sick}}{(V/t)_{well}} = \frac{\left[\frac{d^4}{256}\right]}{\left[\frac{d^4}{16}\right]} = \frac{16}{256} = 0.06$$

partial credit:

5 points for saying maximum capacity means constant V/t, therefore V/t can't change in the constricted windpipe (but −2 points for incorrectly saying velocity increases by a factor of 2)

3 points for saying that maximum capacity means velocity is constant and then correctly calculating vol/t in the constricted windpipe

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ANSWER TWO OF THESE. If you answer more, we will only grade the first two.

a. "A beating cilium works just like the oar of a rowboat." correct: ____ incorrect:____
Why?

b. "When the patient is ravaged by this dreaded disease, his windpipe becomes so inflamed that the diameter of the air passage is only half of what it was before he fell ill. The volume of air per time (V/t) that the sick patient can suck into his lungs when he is breathing at his maximum capacity is cut in half!" correct: ________ incorrect: _______ Why?

c. "When the instructor opens a bottle of perfume at the front of the classroom, the aroma disperses around the room by molecular diffusion. The students in the front row smell it after a few seconds, the students in the middle of the room smell it after about a minute, but the students at the back of the room don't smell it until several minutes have passed."
correct: ________ incorrect: ___X___ ← 1 point Why?

11 pts. { The aroma is spreading across the large distances in the room in a matter of seconds to minutes by being carried in moving air (or you could say the aroma is mixed around the room by turbulence), not by molecular diffusion. Molecular diffusion is a very slow process across large distances

9 pts for saying why it is not diffusion, but without saying that it is due to air movement (or turbulence)

d. When blood is forced from wider blood vessels into narrow capillaries in your circulatory system, it flows at a higher velocity, just like water from a garden hose speeds up when it is forced to flow through the narrow nozzle at the end of the hose. "
correct: ____incorrect:____ Why?

when an incompressible fluid flows through a pipe,

$S_1 U_1 = S_2 U_2$ where S is the total cross-sectional area of pipes in parallel at some position along the pipe and U is flow velocity of the fluid.

11 pts. In the case of the hose, the S of the nozzle is lower than the S of the hose, so the velocity at the nozzle is higher than in the hose. (or they could say the flow speeds up)

However, in the capillaries, the S for all the capillaries in parallel is greater than the S for the larger vessels in the circulatory system, so the velocity in the capillaries is lower (or they could say the flow slows down.

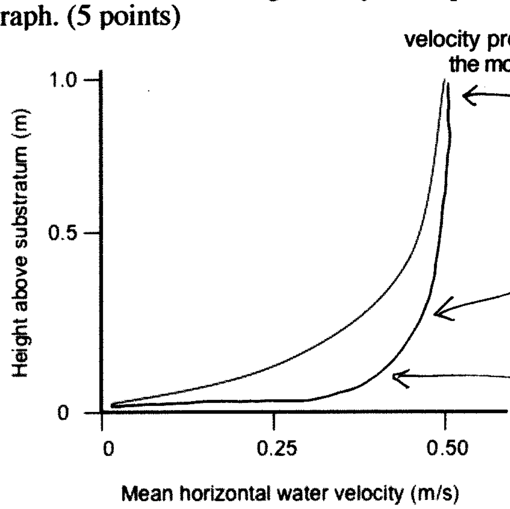
(or full credit if done correctly, but totally in words w/out eqn.)

______5. The graph below shows the mean water velocities you measure in the morning at different heights above the bottom of creek in which the mean freestream velocity is 50 cm/s. During the afternoon, the turbulence in the creek increases because a hundred kids at a summer camp are playing in the creek just upstream from where you are making your measurements. You measure the velocities in the creek during the afternoon, and find that the mean freestream velocity is still 50 cm/s.

a) Would the standard deviation about that mean freestream velocity be greater in the morning or in the afternoon, or would it be the same? (5 points)

The standard deviation of the velocity would be greater in the afternoon. (note: This was explained in an assigned reading...)

b) Draw the velocity profile that you expect to measure **in the afternoon** on this graph. If you think that it will be the same as in the morning, draw your expected curve right on top of the curve already on the graph. (5 points)



(note: 1 point for plotting the same U_∞ (freestream velocity) for both profiles)

full credit for any curve similar to this

(note: 4 points for getting the velocity gradient near the substratum correct)

c) Would diatoms growing on the bottom of the creek be more likely to wash away in the morning or in the afternoon, or would their risk of washing away be the same? Explain your answer. (10 points)

(4 pts. for just this) → They would be more likely to wash away in the afternoon.

The water velocity gradient, $\frac{dU}{dz}$, (where: U = velocity, z = height above substratum) is steeper in the afternoon when the flow is more turbulent.

(6 pts if note that velocity gradient is steeper and shear stress is higher) If the velocity gradient is steeper, then the rate of shear of the water is greater, and thus the shear stress in the water flowing right along the bottom is higher. Therefore the diatoms will be more likely to wash away

or: (6 pts) In the afternoon, the water velocity close to the substratum is higher. Since the drag force on a diatom is proportional to velocity, they would be more likely to wash away. ← (note: diatoms are microscopic and thus experience skin friction drag)

note: -1/4 point if answers given without units if the answer has dimensions
-1/4 point for the wrong number of signif. figures

Name___KEY___________________________

______ 6. A protozoan lives in a small freshwater pond. The protozoan has a diameter of 12 microns (1 micron = 10^{-6} m) and swims at a velocity of 27 microns per second.

a) In July, the water temperature in the pond is 20°C. What is the Reynolds number of the protozoan? (Use the diameter of the protozoan as the linear dimension in your calculation.) (5 points)

$$Re = \frac{\rho U L}{\mu} = \frac{UL}{\nu}$$

U = water velocity relative to protozoan = 27×10^{-6} m/s

L = diameter of protozoan = 12×10^{-6} m

ν = Kinematic viscosity of fresh water at 20°C = 1.004×10^{-6} m²/s

$$Re = \frac{(27\times10^{-6}\ m/s)(12\times10^{-6}\ m)}{1.004\times10^{-6}\ m^2/s}$$

$$Re = 3.2 \times 10^{-4}$$

note: no units → it is dimensionless
note: 2 signif. figures

b) In January, the water temperature in the pond is 0°C, but the pond has **not** yet **frozen** (the water is a fluid). If the protozoan still swims at 27 microns per second in January, is the drag on the protozoan higher or lower than it was during July? By what factor? (5 points)

The protozoan is swimming at low Re, therefore the drag on the protozoan is given by: Drag = $K\mu l u$ where: K = shape constant
μ = dynamic viscosity of the water
l = protozoan diameter = 12×10^{-6} m
u = protozoan velocity = 27×10^{-6} m/s

$$\frac{\text{Drag in January}}{\text{Drag in July}} = \frac{(Klu)(\mu \text{ at } 0°)}{(Klu)(\mu \text{ at } 20°)} = \frac{1.787\times10^{-3}\ kg/(m.s)}{1.002\times10^{-3}\ kg/(m.s)} = 1.78$$

(note: 3 signif figs)

The drag increases by a factor of 1.78
(2 points for simply saying drag increases)

c) You want to measure the drag on a dynamically-scaled physical model of the protozoan to test whether the prediction you made about the drag force is correct. You make a model that is 1 cm in diameter and decide to tow it through water in your bathtub at 20°C. At what speed would have to tow your model to have it operate at the same Re as the protozoan swimming in the pond during the summer? (5 points)

We want to tow the model at a Re of 3.2×10^{-4} (the Re of the protozoan in the summer)

$$Re = \frac{UL}{\nu}$$

where: U = velocity in bathtub
L = model diameter = 1 cm = 1×10^{-2} m
ν = Kinematic viscosity of water at 20°C = 1.004×10^{-6} m²/s

$$U = \frac{Re\,\nu}{l}$$

$$U = \frac{(3.2\times10^{-4})(1.004\times10^{-6}\ m^2/s)}{(1\times10^{-2}\ m)} = 3\times10^{-8}\ m/s$$

(note: 1 signif. fig.)

d) If the speed you calculated in "c)" seems unpractical, briefly describe how you could modify your experiment so that you could tow the model at a more reasonable speed. (5 points)

The velocity is very slow (30 nm/s!).

full credit for this much: I could tow the model more rapidly if I used a fluid with a much higher viscosity than that of water.

(note: 1 bonus point for realizing that the relevant viscosity is the kinematic viscosity, since fluid density is in the numerator and fluid viscosity is in the denominator of the Re equation.)

NOW GO BACK AND CHECK YOUR ANSWERS. ARE YOUR UNITS CORRECT? DID YOU USE THE RIGHT NUMBER OF SIGNIFICANT FIGURES?