Here's an old exam, so you'll have some practice questions.

IB 135 MECHANICS OF ORGANISMS
First Midterm Exam Spring 2004

Note: We purposely have not posted the key. We learned the hard way in the past that many students memorize the answers (which is not helpful) rather than trying to work the problems (which is helpful).

Name: ____________________

Student ID #: ____________________

Section #: ________ Section time: __________

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.

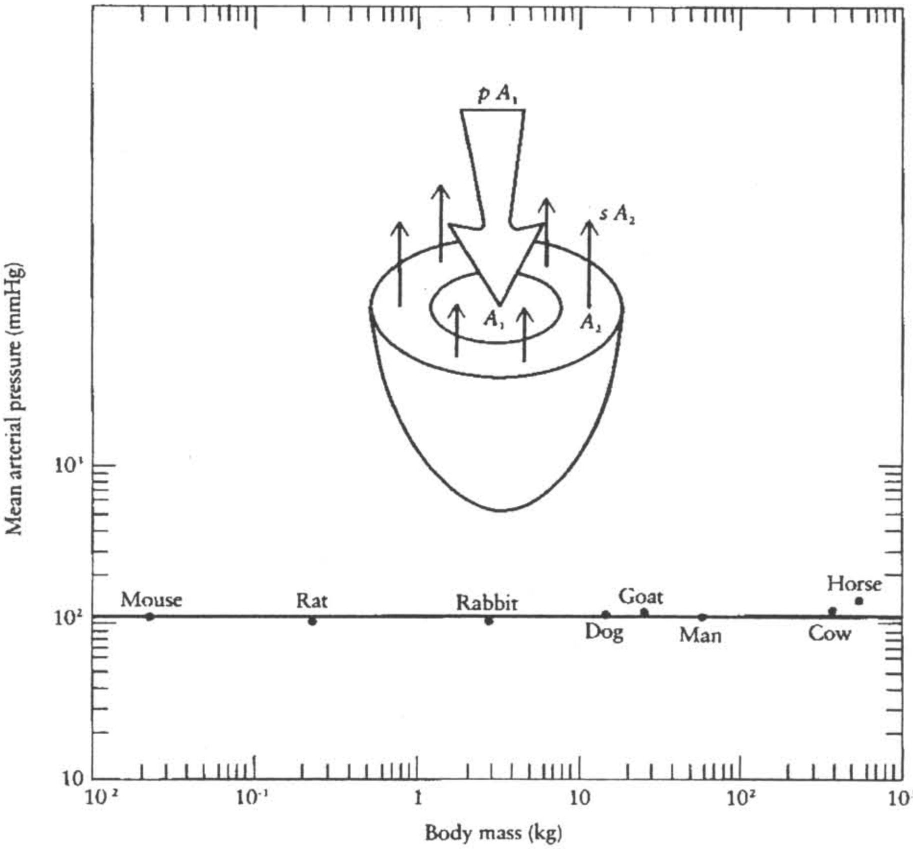
7. Confine answers to the space provided for each.

There are 9 questions on 7 pages. MAKE SURE THAT YOU HAVE THEM ALL.

PAGE	POINTS
2	
3	
4	
5	
6	
7	
8	
TOTAL	

_____ 1. Answer questions a-d below to predict how blood pressure will scale (vary in a regular pattern) with body mass. The diagram below shows a cross-section of a heart. At equilibrium, forces balance. The product of blood pressure in the heart (p) and the area of the cavity (A_1; shown by the big arrow pushing downward) must equal the product of heart muscle stress (s) and the cross-section area of heart muscle (A_2; shown by the many small arrows pulling upward).

$$(p\ A_1) = (s\ A_2) \qquad \text{equation (1)}$$



a) If hearts are geometrically similar, then how does force production by the heart muscle scale with body mass? (2 points)

b) If hearts are geometrically similar, then how does heart muscle stress (s) scale with body mass? (2 points)

c) If hearts are geometrically similar, then how does the heart cavity area (A_1) scale with body mass? (2 points)

d) If hearts are geometrically similar, then how does blood pressure (p) scale with body mass? (4 points)

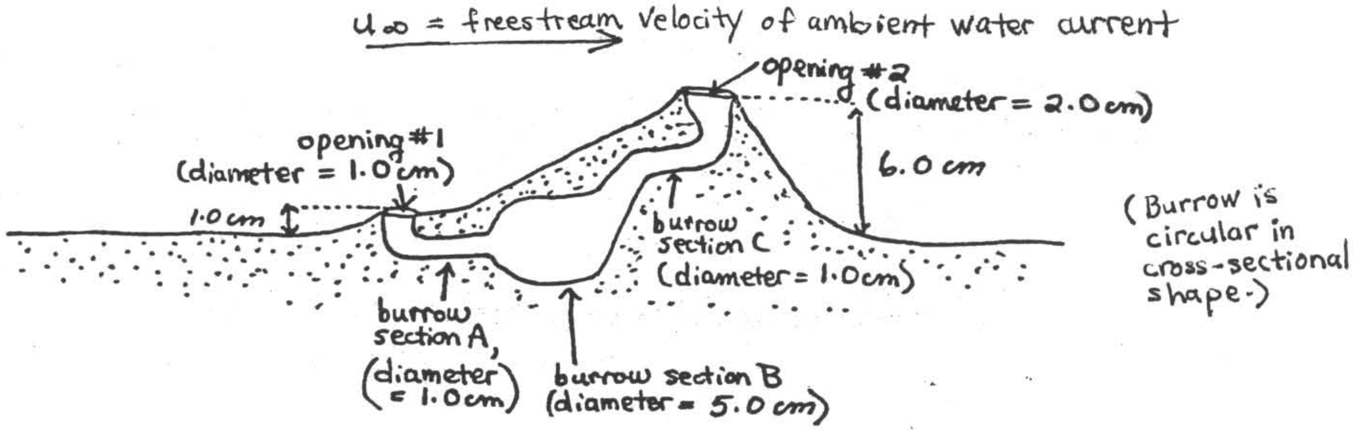
e) Look at the data plotted on the graph on page 2 of this exam. Does blood pressure (mean arterial pressure) scale with body mass as you predict? Why or why not? (2 points)

_____ 2. Drag in water is usually higher than that in air because of the much greater density of water. If the drag coefficient is constant for an object of constant geometry and thus constant cross-sectional area, by what factor must translational velocity of the object decrease in seawater at 20°C relative to that in air at 20°C to obtain an equal absolute drag force in the two media? (5 points)

Don't worry about this question yet. This topic will be covered on midterm #2 this year.

_____ 3. Some snakes are arboreal, and can climb up and down in trees, while other snakes are ground-dwelling and crawl along relatively level horizontal surfaces. Which type of snake (arboreal or ground-dwelling) would you expect to have higher blood pressure? Explain your answer. (8 points)

_____ 4. Here is a diagram of the burrow of a mud shrimp in Bodega Harbor, where it is subjected to gentle tidal currents. A marine biologist squirts some sea water dyed with food coloring into the burrow to see where its openings are located, and then he collects the shrimp.



a) The biologist notices (by watching the food coloring) that water is still flowing through the burrow in one direction after the shrimp has been removed, so the shrimp is NOT pumping the water. Which opening (#1 or #2) do you expect to be the EXCURRENT (i.e. outflow) opening? (1 point)

b) Briefly explain ONE mechanism that might be responsible for the unidirectional movement of water through this burrow when there is no shrimp resident in the burrow to pump the water. (5 points)

c) Compare the volume flow rate (Q) through opening #1 with that through opening #2. (2 points)

d) In which section of the burrow (A or B or C) would you expect fluid pressure on the side walls of the burrow to be the <u>highest</u> ? (2 points)

e) In which section of the burrow (A or B or C) would you expect the pressure on the walls to be the <u>lowest</u> ? (2 points)

f) Explain your answers to d) and e). (10 points)

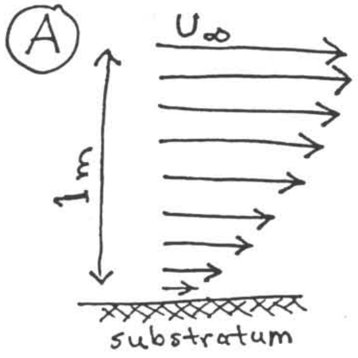
_____ 5. A water beetle can either fly in the air at 5 m/s, or swim in freshwater at 0.3 m/s. The steady-state drag coefficient of the beetle in freshwater is 85% of the value in air. Assuming that both air and freshwater temperatures are 20°C, and given a constant body cross-sectional area, calculate the ratio of power expended to overcome body drag forces in water to the power expended to overcome body drag in air. (10 points)

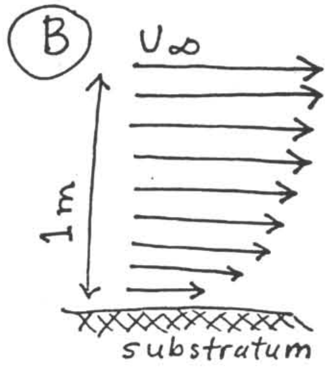
Don't worry about this one yet. This topic will be covered in Midterm #2 this year.

_____ 6. A salmon migrates from the ocean to a freshwater river to spawn. Short-term swelling of the salmon because of osmotic pressure in freshwater causes the cross-sectional area of the body to increase by 15%. Simultaneous decline of energy reserves forces behaviorally a reduction in swimming velocity from 3 m/s in the ocean to 2 m/s in the freshwater river. If we assume a 20°C water temperature in both ocean and river, a constant body drag coefficient, and steady-state hydrodynamic drag acting on the body, by what factor does body drag change in the river relative to that in the ocean? (10 points)

Don't worry about this one yet. This topic will be covered in Midterm #2 this year.

_____ 7. The water velocity profiles above a sand flat in Tomales Bay are diagrammed below. One profile was measured at study site A, and the other was measured at study site B.





The arrows, which represent velocity vectors, are drawn to the same scale in A and B.

U_∞ = freestream velocity

a) Which of the velocity profiles shown above has a higher boundary shear velocity, U_* (velocity profile A or velocity profile B) ? __________ (2 points)

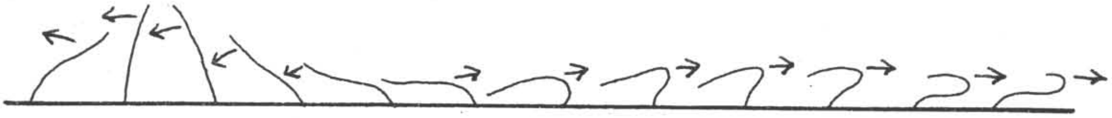
b) Consider some benthic (bottom-dwelling) diatoms (single-celled algae) living on the substratum in the bay. In which habitat (A or B) would the diatoms be MORE LIKELY to be washed away by the ambient water current? __________ (2 points)

Briefly explain your answer. (6 points)

c) In which habitat would the population of benthic diatoms be MORE LIKELY to deplete the water around them of dissolved nutrients? ____________ (2 points)

Briefly explain your answer. (6 points)

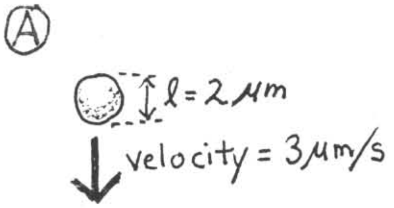
_____ 8. Cilia on epithelial cells of a large organism are beating as diagrammed below. The small arrows by the cilia indicate the directions the cilia are moving.

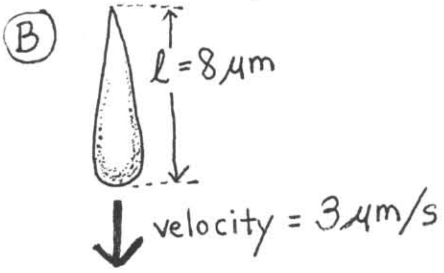


a) The beating cilia are moving water past the ciliated epithelium. Draw a big arrow ABOVE THE CILIA THAT ARE DOING THEIR POWER STROKE indicating the direction that the water is flowing relative to the epithelium. (2 points)

b) Briefly explain how the beating back and forth of a cilium can produce net water flow in one direction at low Reynolds number, where inertial forces are unimportant (things don't coast). (5 points)

9. Two micro-organisms are diagrammed below. The arrows indicate their velocity vectors as they fall through water at 20°C. Their lengths (l) are also shown on the diagrams.





a) On which organism will the drag force be GREATER (organism A or B)? Explain your answer in one or two sentences. (5 points)

Don't worry about this one yet. This topic will be covered on midterm #2 this year.

b) If the length (l) of A were 2m and the length of B were 8m, and if they were falling at 3m/s, which organism (A or B) would experience the greatest drag? Explain your answer in a few sentences. (5 points)

Don't worry ..... later.....

page 1-A

APPENDIX

– 2004 midterm #1

on earth: acceleration due to gravity = 9.807 $m \cdot s^{-2}$ = g

weight = (mass)(g)

S.I. prefixes		
factor by which unit is multiplied	prefix	symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ

SI values of some physical parameters at atmospheric pressure

		dynamic viscosity ($kg\ m^{-1}s^{-1}$)	density ($kg\ m^{-3}$)	kinematic viscosity (m^2s^{-1})
Air	0 °C	17.09×10^{-6}	1.293	13.22×10^{-6}
	20 °C	18.08×10^{-6}	1.205	15.06×10^{-6}
	40 °C	19.04×10^{-6}	1.128	16.88×10^{-6}
Fresh water	0 °C	1.787×10^{-3}	1.000×10^3	1.787×10^{-6}
	20 °C	1.002×10^{-3}	0.998×10^3	1.004×10^{-6}
	40 °C	0.653×10^{-3}	0.992×10^3	0.658×10^{-6}
Sea water*	20 °C	1.072×10^{-3}	1.024×10^3	1.047×10^{-6}
Acetone	20 °C	0.326×10^{-3}	0.792×10^3	0.412×10^{-6}
Glycerin	20 °C	1.490	1.261×10^3	1.182×10^{-3}
Glycerin (90% aq.)	20 °C	0.219	1.235×10^3	0.177×10^{-3}
Mercury	20 °C	1.554×10^{-3}	13.546×10^3	0.115×10^{-6}

*Sea water of salinity 34.84‰. The salinity of sea water varies somewhat from place to place. At 10 °C the dynamic viscosity of sea water is 1.391×10^{-3} and at 30 °C it is 0.868×10^{-3}.

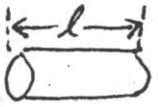
Common quantities, fundamental dimensions, and SI units

quantities	*dimensions*	*SI units*
Length, distance	L	meter (m)
Area, surface	L^2	square meter (m^2)
Volume	L^3	cubic meter (m^3)
Time	T	second (s)
Velocity, speed	LT^{-1}	meter per second ($m\ s^{-1}$)
Acceleration	LT^{-2}	meter per second squared ($m\ s^{-2}$)
Mass	M	kilogram (kg)
Force	MLT^{-2}	newton (N or $kg\ m\ s^{-2}$)
Density	ML^{-3}	kilogram per cubic meter ($kg\ m^{-3}$)
Work	ML^2T^{-2}	joule (J or N m)
Power	ML^2T^{-3}	watt (W or $J\ s^{-1}$)
Pressure, shear stress	$ML^{-1}T^{-2}$	pascal (Pa or $N\ m^{-2}$)
Dynamic viscosity	$ML^{-1}T^{-1}$	pascal second (Pa s or $N\ m^{-2}\ s$)
Kinematic viscosity	L^2T^{-1}	square meter per second ($m^2\ s^{-1}$)

for a circle: circumference $= 2\pi r$ where: $\pi = 3.14$

area $= \pi r^2$ r = radius

for a circular cylinder:



volume $= \pi r^2 l$ where: l = cylinder length

for a sphere: volume $= \frac{4}{3}\pi r^3$

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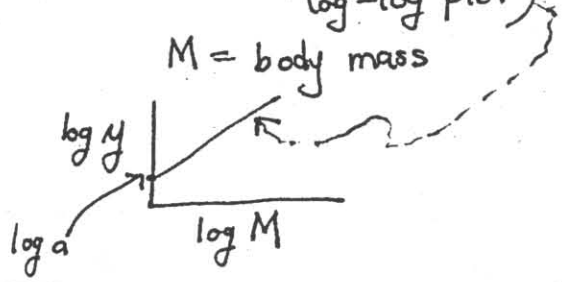
consider body size: $y = aM^b$ where: b = slope of the log-log plot

$\log y = b \log M + \log a$

M = body mass



Stress = force/(area of material resisting that force) $= F/A$

for a Hookean solid material being sheared:
(i.e. G is independent of θ)

shear stress $= \left(F/A\right) = G\theta$ where: G = elastic modulus of the material

θ = shear strain

for a Newtonian fluid being sheared:
(i.e. μ is independent of strain rate)

shear stress $= \left(F/A\right) = \mu \frac{d\theta}{dt}$ where: μ = dynamic viscosity of the fluid

$\frac{d\theta}{dt}$ = shear strain rate

Reynolds number $= Re = \frac{\rho U L}{\mu}$ where: ρ = fluid density

U = velocity

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

L = linear dimension

μ = dynamic viscosity of the fluid

ν = Kinematic viscosity of the fluid $= \mu/\rho$

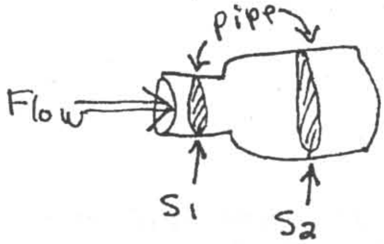
Principle of continuity:

When an incompressible fluid flows through a pipe,

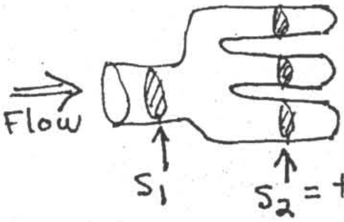
$$\left(\frac{\text{Volume}}{\text{time}}\right)_1 = \left(\frac{\text{Volume}}{\text{time}}\right)_2 = Q$$

$$S_1 U_1 = S_2 U_2$$

where: Q = Volume per time flowing through the pipe
S = pipe cross-sectional area
U = fluid velocity
1 & 2 = subscripts denoting positions along the pipe



or



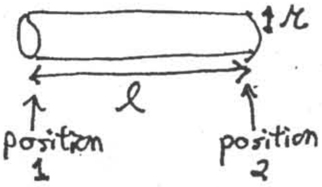
S_2 = total x-sxnal area of all the pipes in parallel at position 2

Poiseuille's equation:

when a viscous fluid flows through a pipe:

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

where: Q = volume per time flowing through the pipe
l = length of pipe
μ = dynamic viscosity of the fluid
r = radius of pipe
ΔP = difference between the pressure at position 1 and position 2 (i.e. How hard you have to push the fluid to drive it through that length of pipe at volume flow rate Q)



Bernoulli's principle

(for an *ideal* fluid, i.e. a fluid with *no* viscosity)

$$\text{energy/vol. of fluid} = \text{constant} = \tfrac{1}{2}\rho U^2 + P + \rho g h$$

or

$$\tfrac{1}{2}\rho\left(U_2^2 - U_1^2\right) + \left(P_2 - P_1\right) + \rho g\left(h_2 - h_1\right) = 0$$

where: ρ = fluid density
P = pressure
U = velocity
g = acceleration due to gravity = 9.807 m/s²
h = height

subscripts 1 and 2 refer to two different positions along a pipe, or along a streamline

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at *low* Reynolds number, skin friction drag:

$$\text{skin friction drag} = k \mu l U$$

where: k = constant that depends on the shape and orientation of the body
μ = dynamic viscosity of the fluid
l = linear dimension of the body
U = velocity of the fluid relative to the body

Stokes Law (skin friction drag on a sphere at *low* Reynolds number)

$$\text{skin friction drag} = 6\pi \mu r U$$

where: r = sphere radius
π = 3.14

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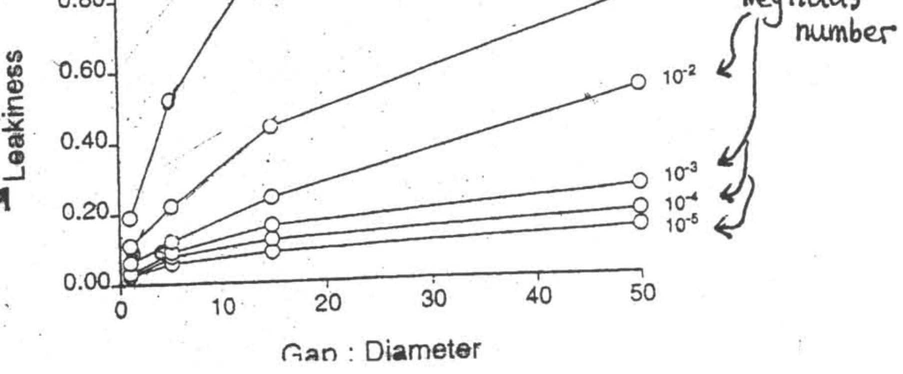
for a row of hairs moving through a fluid:

$$\left[\frac{\left(\text{vol. of fluid flowing through the gap between two hairs}\right)}{\left(\text{vol. of fluid that would flow through a space as wide as the gap } \textit{if} \text{ the hairs were not there}\right)}\right] \leftrightarrow \text{Leakiness}$$



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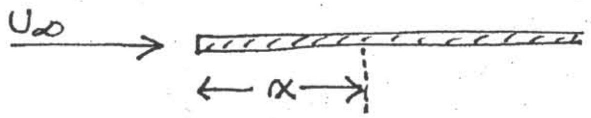
when a viscous fluid flows along a flat plate



The thickness of the boundary layer (δ) at a position at distance x from the leading edge of the plate is given by

$$\delta = 5\sqrt{\frac{x\mu}{\rho U_\infty}} = 5x\sqrt{\frac{1}{Re_x}} = 5x\left(Re_x\right)^{-1/2}$$

where: x = distance from leading edge
μ = viscosity of fluid
ρ = density of fluid
U_∞ = freestream velocity
$Re_x = \dfrac{x\rho U_\infty}{\mu}$

... <u>if</u> the boundary layer is laminar; i.e. if $Re_x < 10^5$

The thickness of the boundary layer at position x is given by

$$\delta = 0.38\,x\sqrt[5]{\frac{1}{Re_x}} = 0.38\,x\left(Re_x\right)^{-1/5}$$

... <u>if</u> the boundary layer is turbulent; i.e. if $Re_x > 10^5$

"law of the wall" ~~for a turbulent boundary layer:~~

$$U_z = \frac{U_*}{K}\ln\left(\frac{Z}{Z_o}\right)$$

where: U_z = velocity at height "Z" above the substratum
U_* = boundary shear velocity
Z = height above the substratum
Z_o = hydraulic roughness height
K = Boltzmann's constant = 0.41

force = mass x acceleration
power = force x velocity

$L = 0.5\ \rho\ C_L\ S\ V^2$
L: lift
ρ: density
C_L: lift coefficient
S: cross-sectional area
V: velocity

$D = 0.5\ \rho\ C_D\ S\ V^2$
D: drag
ρ: density
C_D: drag coefficient
S: cross-sectional area
V: velocity

density of fresh water, 20 deg. C: 0.998×10^3 kg/m^3
density of seawater, 20 deg. C: 1.024×10^3 kg/m^3
density of air, 20 deg. C: 1.205 kg/m^3