The University of British Columbia

Examination – Spring session 2006

BIO/P 438

Time 2 1/2 hrs

Candidates Name:...

Registration #:......................................

Candidates Signature ....

This is an open book exam
& you can use "Zoological Physics", and your own lecture notes

The exam has 4 parts (pages 1-9);
Make sure that you have a complete exam with all 9 pages

Part A: Attempt 1 out of 6 questions
Part B: Attempt this question
Part C: Write an essay on one of the topics
Part D; Poster question

show all your rough work

	A: select 1 out of 6			Part B	Part C	Part D	Final mark
Question	1 2	3 4	5 6	Whale	essay	Poster	
max. mark	25	25	25	35	25	15	100
mark							

If you think some necessary information is missing from the exam or from the text book make an "educated guess"
namely quote a number and write down why this number would make sense.
Your clarifying comments may earn you bonus points.

When you use a number from the text book please quote the page number.

Having a new and creative thought is wonderful, but don't expect glory.
Just enjoy if your idea lives on and is used by others
The rewards go to the ones who come second.
Pioneers get arrows into their bums

A1) Thermodynamics; A Horse and buggy story

A farmer (M=90kg when fully dressed) owns a horse of M_h=300kg.
(a)What is the metabolic rate of the horse on a day when it is just standing in the stable, not doing any work? And how much energy does it require per day?
(b) The farmer feeds the horse 1.2 kg of oats (Δh_{oats}=14MJ/kg and hay (Δh_{hay} = 300kJ/kg). How much hay does the farmer have to give the horse to support it's basic metabolic rate?
(c) When the horse is working it operates with an activity factor b=5.5 and an efficiency η=24%. What is it's mechanical power output P[Watt] Express your result in watt and horsepower (1HP=750watt); and how much heat [Watt]does the horse generate per second.
(d) The farmer uses the horse to draw a cart M_c=80kg, loaded with 2 bags of grain M_g=60kg each, up to a cattle feedlot, which is located on a little hill, h=75m high. Of course he sits on the cart as well. How much mechanical (potential) energy does the horse have to generate on this trip?
(e) How much heat does the horse generate on this trip, and how much sweat (water) would the horse evaporate if it kept its temperature constant sweating.
(f) How long does it take the horse to make the trip?
(g) If the road to the feedlot has a gentle constant slope of 5%, how long this the road? Length of road s. heights h; (h) At what speed does the cart travel?
(i)Considering your result from (c). Can you think of a reason why engineers often use the unit 1Horse Power (1HP=750W)?

(a) $\Gamma_o=3.6\cdot 300^{3/4}=259.5W$. *At 86400s/day* $\Delta Q= 259.5J/s \cdot 86400s=2.24\cdot 10^7 J$.
(b) $\Delta Q=\Delta h_{oa}\cdot m_{oats} +\Delta h_h\cdot m_{hay}$ *in numbers* $2.24\cdot 10^7 J=1.4\cdot 10^7 J/kg\cdot 1.2kg+3\cdot 10^5 J/kg\cdot m_{hay}$. *Solve for* m_{hay}= 18.7kg *of hay*
(c) $P= b\eta\Gamma_o=259.5W\cdot b=5.5\cdot 0.24=3.38\cdot 10^2 W=0.45Hp$. *Heat output* $\Delta Q'= (1-\eta)b=0.76\cdot 5.5\cdot 259.5W=1083W$.
(d) *Potential energy* $E_{pot}= (M_{cart}+M_{farmer}+M_{grain}+M_{horse})\cdot g\cdot h=(80+90+120+300)\cdot 9.81\cdot 75=4.34\cdot 10^5 J=\Delta W=\eta\Delta Q$.
(e) *Total energy generated* $\Delta Q=\Delta W/\eta=4.34\cdot 10^5 J/0.24=1.809\cdot 10^6 J$. *Heat* $\Delta U= \Delta Q-\Delta W= 1.375\cdot 10^6 J$
$\Delta U=L_v\cdot m_{water}$. Hence $L_{vapor} = \Delta U/L_{vapour}$ = $1.375\cdot 10^6 J/2257J/g°$=609g water
(f) $\Delta W=P\cdot\Delta t$, *hence* $\Delta t=\Delta W/P= 4.34\cdot 10^5 J/3.38\cdot 10^2 W.=1287s=21.5min$
(g) *sin* $ø$ $=h/s=0.05$, *thus* $s= 75/0.05=1500m$.
(h) $U=s/\Delta t=1500m/1287s=1.166m/s$
(i) *Presumable a horse can generate about double the output calculated above, (namely about 1Hp) in short burst of power..*

A2) Statics Toeholds

A person of M=80kg is standing with one foot on a book, as shown. (a) Determine the tension T (force) in his Achilles tendon (diameter d=8mm), which is held by the calf muscles (A=90cm^2), and give the stress (F/A) in the muscles. (b) Calculate the tension T if the foot is in the horizontal position (ø=0°).

(c) For ø=0° calculate the stress $\sigma=T/A_t$ in the tendon, and determine the safety margin, namely how much smaller σ is than the maximum yield strength of tendon material.

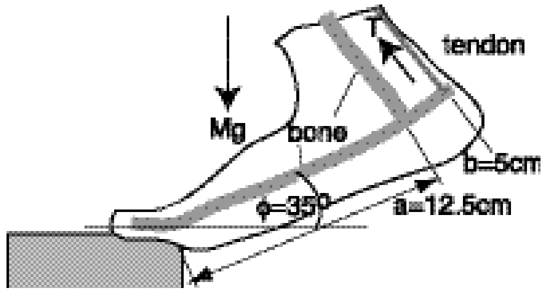


Fig. 2. Toehold

A3 Fluids: **Is the lung ideal?**

The lung of a typical person of M=75kg has a volume of V=5liter, and during exhaling it is reduced in volume by up to 13%. The air is admitted through the windpipe, a tube of $L\approx$20 cm length and $R\approx$0.8cm radius. The O_2 and the CO_2 molecules are exchanged in a huge number of alveoli, tiny bubbles of $r\approx$100μm radius. Assume allometric scaling according to Table 11.21, page 1-5. $\nu_{blood}=4\cdot 10^{-6}$m²/s

Hagen Pouiseulle equation $m' = (\pi R^4/8\nu)\cdot(p/L)$

(f) What is the allometric breathing frequency. What is the exhaling time interval?
(g) What is exchanged volume ΔV_{ex}, and how large is the volume flow φ. [m³/s]?
(h) What is the flow velocity, what is the Reynolds number Re? Is the flow in the windpipe laminar or turbulent?
(i) How large a pressure drop Δp is needed to drive the volume flow through the windpipe?
(j) How many molecules of oxygen are in 1m³ of freshly inhaled air, and how many oxygen molecules are in a single alveola ?
(k) Explain qualitatively why the lung has so many alveoli. Give some reasons why the radius r of the alveolae is $r\approx$100μm, and not much smaller and not much larger.

(a) $f_{br}=0.892\cdot M^{-0.26}=0.892\cdot 75^{-0.26}=0.29$Hz. *Period* $T = 1/f=3.44$sec., *inhale or exhale in* $\Delta t\approx T/2=1.72$s

(b) $\Delta V=0.13\cdot V=0.13\cdot 5\cdot 10^{-3}m^3.=0.65\cdot 10^{-3}m^3$, *volume flow* $\varphi\approx\Delta V/\Delta t=0.65\cdot 10^{-3}m^3/1.72s= 3.77\cdot 10^{-4}m^3/s.=377cm^3/s$. *This is much larger than the metabolic minimum flow rate of* $\varphi_{met}=37cm^3/s$

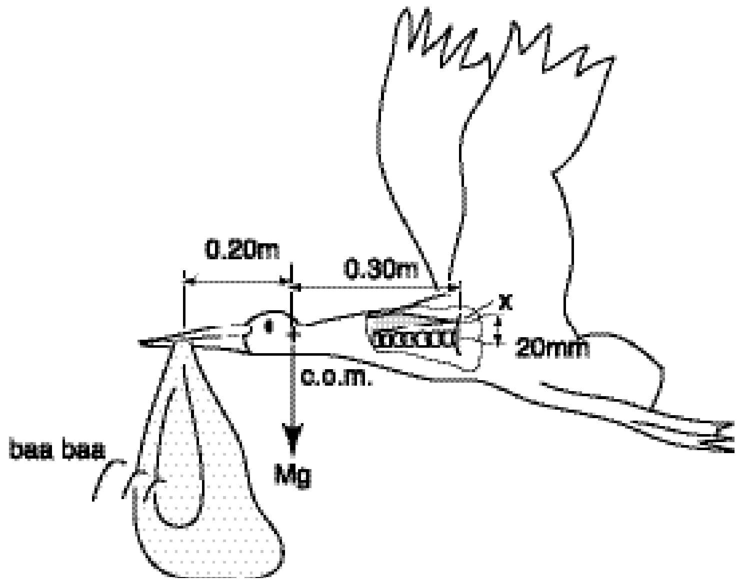
(c) Volume flow $\varphi=A\cdot u$, *where* $A= \pi R^2.= \pi\cdot(8\cdot 10^{-3})^2=2.01\cdot 10^{-4}m^2$.
Hence $u=\varphi/A=3.77\cdot 10^{-4}m^3s^{-1}/2.01\cdot 10^{-4}m^2=1.88m/s$. *Then* $Re=u\cdot 2R/\nu=1.88m/s\cdot 0.016m/4\cdot 10^{-6}m^2/s=7522$
turbulent. However in normal operations one uses only about 1/10 of the volume flow, then u= 0.188m/s, and Re = 750. Then the Reynolds number stays well below the critical Reynolds number Re ≈2500.

(d) For turbulent flow solve equation (42.63) for Δp, *for laminar flow use (42.32) to determine* Δp.

(e) $N_{O2}=5\cdot 10^{24}O2/m^3$. *Radius of alveola* $r\approx 100\mu m$. *Volume of one alveola* $V_A=(4\pi/3)r^3=4.19\cdot 10^{-12}m^3$. *Total number in 1 alveola* $N_a= V_A\cdot N_{O2}= 5\cdot 10^{24}O2\cdot m^{-3}\cdot 4.19\cdot 10^{-12}m^3=2.09\cdot 10^{13}O2$.

(f) The lung need s so many alveolae in order to have a large surface area for the oxygen exchange by diffusion. If the alveolae were much smaller they would not hold enough oxygen to exchange during one breathing cycle. If they were much larger the oxygen could not diffuse quickly enough to the surface

A4 Dynamics Stork on duty



A stork of body mass M_o=9.4 kg is battling the laws of physics to deliver baby Liam. The combined mass of the stork's head and neck is 0.8 kg with its center of mass (COM) located just behind its head. Added to this is the 2.5 kg mass of the baby, held in the beak 200 mm in front of the COM. The stork has to hold its payload using a muscle that runs just above the spine the length of its neck, 300 mm. The muscle attaches to the head at the same spot that the spine attaches, but at the "shoulders" it attaches to a bone 20 mm above the spine.

a) What is the resting metabolic rate Γ_o of the stork?
b) What is the speed u_o at which the stork (mass M_o) would fly without the baby?
c) Assuming a lift coefficient C_L=1.2 how large a wing area A of the stork to cruse at u_o?
d) Assuming a frontal surface area of A_f = 0.02 m^2, and C_D=0, what is the drag force F_D and the mechanical power $P = b\,\Gamma_o$ and the activity factor b at the speed u_o ?
e) At which speed u_1 must the stork fly when carrying Liam?
f) What is the tensile force on the neck muscle?

A5 Sound Sound of pain

A mosquito flips its wings at f=120Hz. You can barely hear the mosquito from a distance of r=3m. Assuming that "barely hear" is equivalent with an intensity at your ear of 5 dB. (Speed of sound v=340 m/s)
(a) Find the intensity I_1 at the location of your ear.

(b) Estimate the surface area of you ear and calculate how much power you ear intercepts.
Assume $A_{ear} \approx 30\text{cm}^2 = 3\cdot 10^{-3}\text{m}^2$. Intercepted power (c) How much sound power does the mosquito radiate into all direction as it makes this noise?

(d) What is the pressure fluctuation amplitude Δp_o , the displacement amplitude s_o and the velocity amplitude u_o of the sound waves in the air near your ear?

(e) Suppose the wing tip moves up and down in simple harmonic motion with an amplitude of A= 1.50mm (peak to peak amplitude 3mm). Calculate the velocity U of the wing tip of the mosquito and compare it to u_o (namely calculate the ratio U/u_o.)

Also determine the ratio A/s_o.

(Comment: Amazing how small u_o is compared to U, and how small s_o is compared to A !!!)

(a) *I: 5dB=10log*$_{10}${*I/10*$^{-12}$*W/m*^{2}} *5/10=0.5=log{ }; thus 10*$^{0.5}$*=3.16=10*$^{log\{\}}$*=I/10* $^{-12}$ *, hence I=3.16·10*$^{-12}$ *Watt/m*^{2}…

(b $P_{ear}= A_{ear}\cdot I= 3.16\cdot 10^{-12}$ Watt/m$^2\cdot 3\cdot 10^{-3}$m^2=9.5·10^{-15}W.

(c) *At location of ear where r=3.0m one has* $I=P/4\pi r^2=3.16\cdot 10^{-12}$ Watt/m^2 . *Solve for* $P= I\cdot 4\pi r^2=3.16\cdot 10^{-12}$ Watt/m$^2\cdot 4\pi\cdot 3^2$m^2= 3.57·10^{-10} W

(d) $\Delta p=\sqrt{2\rho v I} = (2\cdot 1.29\text{kgm}^{-3}\cdot 340\text{m/s}\cdot 3.16\cdot 10^{-12}\text{ Watt/m}^2)^{1/2}= 5.26\cdot 10^{-5}\text{ N/m}^2$, *and* $\rho v= 439\text{kg/m}^2\text{s}$.

particle speed: $\Delta p= \rho\cdot v\cdot u_o$, thus $u_o=\Delta p/\rho v=5.26\cdot 10^{-5}\text{ N/m}^2/\ 439\text{kg/m}^2\text{s } 9 = 1.20\cdot 10^{-7}\text{m/s}$.

Displacement amplitude $s_o=(1/2\pi f)\sqrt{\{2I/\rho v\}}=(1/2\pi\cdot 120)\sqrt{\{2\cdot 3.16\cdot 10^{-12}/439\}}= 1.59\cdot 10^{-10}\text{m}$.

(e) $U=A\cdot\omega= 1.5\cdot 10^{-3}\text{m}\cdot 2\pi\cdot 120=1.13\text{m/s}^6$

$U/u_o =1.13\text{m/s}/1.20\cdot 10^{-7}\text{m} /= 9.4\cdot 10^6$

$A/s_o =1.5\cdot 10^{-3}\text{m}/1.59\cdot 10^{-10}\text{m}=9.4\cdot 10^6$

A6 - Optics Eye damage

Roy Nodwell, head of the Physics Department UBC from 1978 to 1983 had a damaged retina in one of his eyes. When he was a small boy he watched a partial solar eclipse occurred in his native Saskatchewan. Assume that the moon covered 40 % of the sun's disk. Everyone used a piece of glass blacked with soot as a filter to cuts down the intensity of the sunlight. Little Roy wanted so see more and looked straight into the sun without a glass filter. The eye naturally contracts the iris in bright light, assume that Roy's pupil contracted to a diameter of d=0.8 mm.

(a)Assume that Roy looked at the sun for the 2 minute that it took the moon to cross before the sun How much energy E_{phot} [J] would pass through his iris during this time

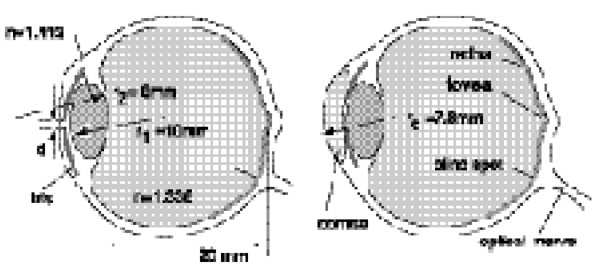
(b) Calculate the number of photons (average photon energy of yellow light of $E_p\approx 3.4\cdot !0^{-19}$ J.

(c) The sun subtends an angle ø≈ 1/2 ° How large was the burnt area of Roy's retina?

(d) What would be the radius of curvature r_1 when focussing at the sun? .

(e) Suppose his iris contracted to a diameter of d= 0.9 mm. What was the width of the diffraction spot created by the iris on his retina

Assume that the radii of the eye lens are always kept the ratio r_2/r_1= 6/10= 0.6.



(f) (g)

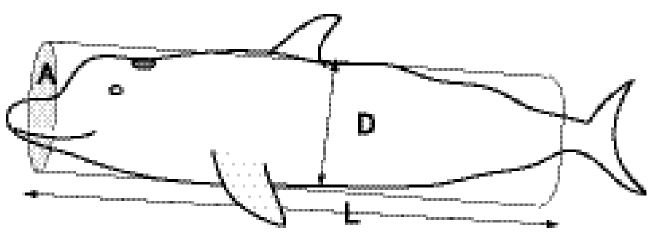
f) Suppose the cornea did not contribute to the imaging, Fig. (f), What would be the radius of curvature $r_2 = 0.6\ r_1$?

g) But of course, the cornea does contribute to the focussing, sketch Its radius is kept constant at r_c= 7.8 mm, and the fluid contained by it is water with n= 1.33. What is r_1 in this more realistic case?

Part B ♦♦♦ attempt all parts of this problem ♦♦♦ **marks 35/100**

Killer Whales

A common dolphin of M=120kg can jump up into the air raising its center of mass by H=2.40m above the surface of the water, and it can easily dive down to D_1=65 m depth. Dolphins have a streamlined body with the diameter to length aspect ratio D/L≈ 0.25 of a fast swimmer. Dolphins talk to each other by whistling calls, and they explore their surroundings by sonar clicks.



b) What is its metabolic rate if the dolphin has an activity factor b=6? How many sardines (mass m= 7g ,) does the dolphin have to eat daily to support its metabolism? (for the sardines you may take an average heat of reaction Δh≈ 23 kJ/g)

Γ= 6*3.6*120^0.75=783.1W

= Per day E/d= 86400s Γ=6.766*10^7

Sardine E=7*23*10^3=1.61*10^5, Sardines per day =420./

c) How much heat does the dolphin loose in the Juan da Fuca street (water temperature T≈ 8°C) through a surface section (A= 300 cm^2) on its belly where it is insulated by a Δx=6cm thick layer of body fat? . Assume Th=36° Q'=k*A*ΔT/Δx= 0.2W/°m*3*10^-2m^2 *(36-8)/0.06m=2.8Watt Assume Th=

d) .Comment on the fact that flippers do not have much body fat insulation. Would not the animal lose much heat from the flippers? Flipper likely have counter flow heat exchangers, and are cold appendages of a warm body

e) How fast does the dolphin have to swim when leaving the water to reach a center of mass height of H=2.4m. Mgh = 0.5 M u^2, thus u=√2gh= √2* 9.81*2.4m = 6.86 m/s

f) If the dolphin swims at a speed u= 4.5 m/s what would be its drag resistance? (take C_D=0.02) M= ρ0.25*πD^2*L=120kg, ρ≈100kg/m^3 Dolphins are fast swimmers so that X=D/L=0.25, or L=4D, then 120kg=ρ0.25*πD^2*L= =ρ0.25*πD^2*4D= ρ*πD^3, or D^3=120/(πρ), D= 0.337m, A= π*0.25D^2=8.9*10^{-2}m^2 F_d= 0.5 A C_d*U^2= 0.5 X=

g) What is the pressure in the water at D_1= 65 m depth?

h) Suppose the dolphin dives in murky water (absorption coefficient κ = 0.15 m^{-1} to the depth D_1 at a cloudy day when the light intensity is 40 % of the average solar intensity S=1.37 kw/m^2. What is the intensity at that depth? How many photons per second would pass through the dolphin's iris (assume an iris diameter d= 1.4cm) when looking straight up from that depth?

i) The dolphin emits a whistle of the intensity I=10^{-3} Watt/m^2 at the frequency f= 8.5kH. What is the wavelength λ and the sound level β in dB (re I_o=10^{-12} Watt/m^2) of this sound wave?

j) The dolphin also can emit sonar clicks for locating its prey. How long does it take the sound to travel back and forth to a target that is Δz= 2.3 km away?

Part Ca

35/100 mark

Write an Essay **(typically 200- 300 words) on one of the topics**

All essays must include relevant equations

a) How might insects control their body temperature?
b) Discuss how animals use sound for communication in the air, and in the water.
c) Is there a best sense for an animal? (Why do some animals mainly rely on their ears, other on their eyes, or detect electric and magnetic fields, and others on their sense of smell?)
d) Describe some examples of resonance used by animals in locomotion and/or sound production.
e) Describe some of the physical principles which one of the animals below uses to survive in their niche: alligator, bat, crow, dolphin, honey bee, monkey, octopus, pit snake, shark, wolf

Part Cb

Poster

To be finalized (15/100 marks)