**The University of British Columbia**

**Examination – Spring session 2005**

**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 | Casey | 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

**Part A:** Solve 1 out of the following 6 questions.

**A1 - Thermodynamics - Energetics**
**New Species discovered**
*fact or fiction?*
From *Discover* **16**(4), 14 (April 1995)"Hot-Headed Moles in Antarctica,".

The field biologist April Pazzo, observed a strange phenomenon while watching Emperor Penguins (M=15kg) at a remote, poorly explored area along the coast of the Ross Sea in Antarctica: a whole flock of penguins sort of stampeded, waddling away faster than she had ever seen them move. But one penguin that hadn't fled was sinking into the ice as if into quicksand,. Somehow the ice beneath the bird had melted; the penguin was waist deep in slush. Pazzo grabbed its wings and pulled. But the penguin wasn't the only thing she hauled from the slush. About a dozen small, hairless pink mole-like creatures had clamped their jaws onto the penguin's lower body. Pazzo managed to capture one of the creatures, it had a slender cylindrical shape, a body weight of 1.2 kg, and it had have a very high body temperature $T \approx 43°$ C. The most fascinating feature was a bony plate about 4 cm in diameter covering the full cross section of their body on their forehead. Innumerable blood vessels line the skin covering the plate. The animal radiates tremendous amounts of body heat through this "hot plate," which it apparently used to melt tunnels in ice and to hunt their favourite prey: penguins, but the animal also floats and swims effortless in water. .

a) How long is the animal's body.
b) If this animal operates at an activity factor b=10 what is its metabolic rate?
c) Suggest how the animal is insulated against heat loss to the walls of its under-ice tunnels, and what it could do to prevent heat loss when not hunting penguins.
d) How much energy does the animal have to expend to melt a 1.0 m long tunnel through the ice?
e) How quickly can the animal generate this heat by its metabolism?
f) Express your answer from part d) as the tunnelling speed of the Hot-headed moles.
g) How many penguins would the hot mole have to eat per week in order to survive?
h) Pazzo continues in his story *" A pack of these ice borers will cluster under a penguin and melt the ice and snow it's standing on. When the hapless bird sinks into the slush, the ice borers attack, dispatching it with bites of their sharp incisors. They then carve it up and carry its flesh back to their burrows, leaving behind only webbed feet, a beak, and some feathers. They travel through the ice at surprisingly high speeds, much faster than penguins can waddle."*
   Do you think the penguins have a chance to escape?
i) Pazzo's discovery may also help solve a long-standing Antarctic mystery: What happened to the heroic polar explorer Phillipe Poisson, who disappeared in Antarctica without a trace in 1837? "I wouldn't rule out the possibility that a big pack of ice borers got him," says Pazzo. "I've seen what these things do to emperor penguins -- it isn't pretty -- and emperors can be as much as four feet tall. Poisson was about 5 foot 6. To the ice borers, he would have looked like a big penguin
   Do you think this explanation is true?

**Solutions**

b) $L = M/\{\rho\ \pi\ R^2\} = 1.2$ kg $/\{1000 kg/m^3 \times 3.14 \times 0.02^2\} = 0.95m$

c) $\Gamma = 10 \times 3.6 \times M^{3/4} = 39.07$ W

d) Insulation by blubber, hair, go into torpor, roll into a ball.

e) To melt a 1.0 m long tunnel through the ice requires the melting the mass $\Delta M = \Delta V \times \rho_{ice} = Am^2 \times 1.0m \times 910kg/m^3$, where $A = \pi\ R^2 = \pi\ 0.02^2$. This implies the energy $\Delta Q = \Delta M \times C_f$, where $C_f = 330 \times 10^3$ J/kg, namely $\Delta Q = 1.0 \times 3.14 \times 0.02^2\ m^3 \times 910 kg/m^3 \times 330 \times 10^3\ J/kg = 4.14\ 10^5$ J

f) At $\Gamma = \Delta Q/\Delta t = 39.1W$ the animal melts thus tunnel in $Dt = \frac{4.14 \cdot 10^4 J}{39.1 J/s} = 1.1 \cdot 10^4 \sec$ .

g) Speed u = 1m/ Δt = 1/ 1.1 104 = 95 μm/s

h) Say 60 % of the penguin is edible with h=4 MJ/kg for meat. Then $\Delta Q = 0.6\ M \times h = 0.6 \times 15kg\ 4\ 10^6$ J/kg $= 3.6\ 10^7$ J. For 1 week $\Delta t_{1w} = 3600 \times 24 \times 7$ the critter hasto eat N penguinsso that $\Gamma = \Delta Q/\Delta t$. Thus

$$N = \frac{G \cdot Dt}{DQ_p} = \frac{39\,W \cdot 3600 \cdot 24 \cdot 7\,s}{0.6 \cdot 15\,kg \cdot 4 \cdot 10^6\,J/kg} = 0.65\ penguins$$

i) Penguins can easily outrun aspeed of as fraction of a mm per second.

j) No

## A2 - Locomotion

### Extinct flying machines

The partial skeleton of a now extinct dinosaur *Pterodactyls phantasiensis elegans* has been excavated. The body had a length of $L$=2m, and an estimated body mass $M$=12.0 kg. The one recovered wing has a wing span of $L_{wing}$=2.4m with an average wing width of $W$=1.1m. Assume a lift coefficient $C_L$=0.6.

a) Determine the velocity that the animal needs to stay aloft

**b)** Compare this speed to the velocity that the animal would have according to the great flight diagram $u_{fl}=17 \cdot M^{1/6}$ . What can you conclude for the activities of the animal if the answer from (b) differs from the answer from (a)

**c)** It is not known if Pterodactyls were capable of powered flight or if they used only gliding flight. Analysis of the power requirement for flight might provide some insights. Calculate the mechanical power required for the Pterodactyl to maintain a constant forward velocity (as calculated in part a) in level flight. Assume a drag coefficient $C_D$ = 0.2, (referenced to the wing surface area S , see pg 96, or eqn. 34.51 from the old lecture notes)

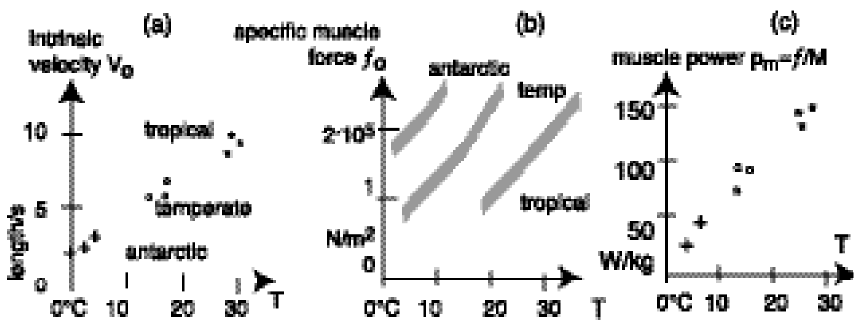



Fig. 3.1. Comparison of tropical, temperate and arctic fish
(a)Contraction velocity , (b) muscle stress, (c) muscle power

d) Now consider if Pterodactyls could generate sufficient muscle output to power level flight. In order to do this, use the muscle power data as shown above. These data are taken from the fast-start (i.e. burst) performance of arctic, temperate and tropical fish, and they are plotted as a function of body temperature. Assuming that Pterodactyl muscles are like those of temperate fish, what fraction of the Pterodactyl's body mass must be flight muscle for the animal to achieve level, powered flight. What muscle temperature have you assumed is required for power flight?

**e)** What in general can you infer about the Pterodactyl's capability for sustained, level powered flight as opposed to burst or transient flight. Now, what can you infer about the dinosaur from your results. Dinosaurs are generally believed to have been cold blooded animals (you may go beyond the physics of motion)

Solutions

**a)** $Mg= 0.5\ C_L\ S\ \rho_{air}\ u^2$, wing area $S=2\cdot 2.4\cdot 1.1m^2=5.28m^2$ solve for

$$u=\sqrt{\frac{12\cdot 9.81}{0.5\cdot 0.6\cdot 5.28\,m^2\cdot 1.29}}=7.6\,m/s$$

**b)** Find u from the great flight diagram or calculate it from $u= 17\ M^{1/6}=17\cdot 12^{3/4}=25.7$ m/s

**c)** $P= F_D\ u$, take u=7.6 m/s and $F_D=0.5C_D\ \rho\ u^2=0.5\cdot 0.2\cdot 1.29kg/m^3\cdot 4.4m^2\cdot 8.3^2=39.1N$,
thus $P=39.1N\cdot 7.6m/s=297W$.
Also note that $F_D/C_D= 0.5\ S\ \rho\ u^2=F_L/C_L$, Thus $F_D=C_DF_L/C_L=F_D/3=Mg/3$.

**d)** Assume that the "bird" had muscles that acted like a "temperate" fish, generating p=100 W/kg, it would have to dedicate the amount of $\Delta m$ muscles so that $\Delta m\cdot p = 297W$, namely

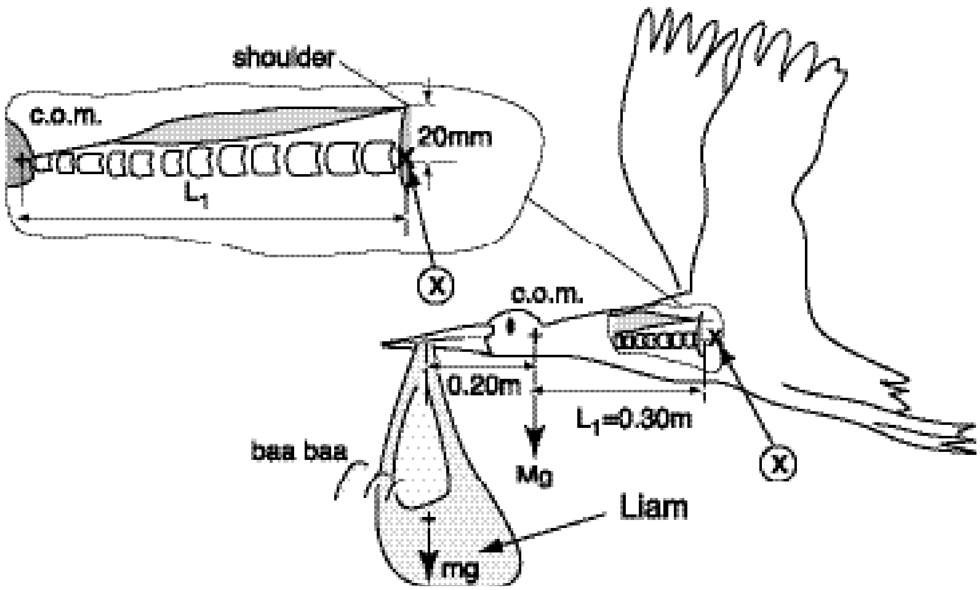
$$Dm=\frac{297\,W}{100\,W/kg} » 3\,kg$$ This is only 1/4 of the total body weight and likely quite affordable.

e) The animal likely would use any up-drifts and thermals to get up and to stay aloft Flapping of these wings might be a problem due to their long length..

**A3 - Statics**

## Stork on duty

A stork is battling the laws of physics to deliver baby Liam. The combined mass of the stork's head and neck is $M$=1.1 kg with its center of mass (c.o.m.) located just behind its head. Added to this is the $m$=2.5 kg mass of the baby, held in the beak 200 mm in front of the c.o.m. The stork has to hold its payload using a muscle that runs just above the spine the length of its neck, $L_1$=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) Calculate the torques acting at the point "x" by the "shoulders".
b) What is the tensile force on the neck muscle?
c) Assuming the muscle holds a static stress of $f = 2 \times 10^5 N/m^2$, what is the muscle diameter?
d) What is the compressive force on the vertebrae and discs?
e) If the disc is loaded to 90% of its maximum compressive stress $Y = 10^7 N/m^2$, what is the disc diameter?
f) Briefly identify any other physics problems particular to stork couriers.

## A4 - Fluid Flow

### The neck of the giraffe

Giraffes with their long necks (length $L$) are able to browse on tall trees, which are out of the reach of most other animals. This definite advantage comes at a price. The long neck makes breathing difficult. The metabolism $\Gamma = b \times 3.6 M^{3/4}$ requires a certain intake of fresh air. The windpipe volume $V_w = \pi R^2 L$ must be filled first when exhaling, before any air volume $V_{ex}$ can be exchanged and reloaded with oxygen. The flow should not be turbulent in the windpipe. Consider a giraffe of M=2000kg operating at an activity factor b=3

a) How much air $\varphi$ = [$m^3/s$] must reach the lung per second in order to have sufficient oxygen? The relevant equation was derived in class, it is given in the book as eqn. (4.21), but that equation has a printing mistake:
 a minus sign is missing: It should be$10^{-6}$, namely $\varphi = (\Delta V_{metabolism}/T) = 1.5 \times 10^{-6}\, b\, M^{3/4}$

f) Assume an allometric relation for the breathing frequency $f = 0.9 M^{-1/4} s^{-1}$, (as given in Table 1.2, page 14) find the breathing period T=1/f, and find the volume of fresh air $\Delta V_{ex}$ that must reach the alveoli in one breath to support the metabolism .

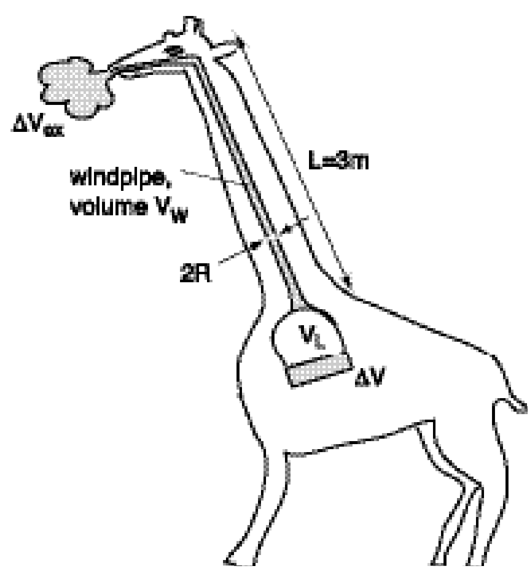
g) However, of the total volume $\Delta V_L$ displaced by the lung in one single breath $\Delta V_L = V_w + V_{ex} = 0.14\, V_L$.
Only the component $V_{ex}$ reaches the outside to allow the exchange of fresh air, the other component $V_W$ remains in the windpipe. $\Delta V_L$ is a certain fraction $\Delta V_L = 0.14\, V_L$ of the lung volume $V_L$ , which in turn is allometrically related to the body mass M, namely $V_L = 5.7 \times 10^{-5} M$ [$m^3$ of gas]).
Calculate $V_L$ and Vw.

h) Find the windpipe radius R for a certain giraffe with a windpipe length L=3.0 m.

i) What is the Reynolds number Re based on the average air flow velocity in the windpipe.

j) Comment on the physical and biological significance of Re, which you have calculated in part (e).P

k) What is the minimum blood pressure that the heart must generate so that the blood will reach the head when head is 3m above the heart?



## A5 - Sound

**Bat's best behaviour**

a) Suppose a **mustached bat** emits a short "click" of 1.5 msec duration, and of such a vocal power P that it produces the intensity ß= 90dB at the distance r= 2.3 m, where a moth is located. What is the sound intensity (emitted by the bat into the direction of the moth) at close distance, say at $r_0$=20 cm?

b) If the moth presents a target of A= 1 $cm^2$ and it reflects 40% of the sound from the bat how much energy is reflected back towards the bat, during one click ?

c) How much of the reflected power would the bat's ears (surface area $A_b$ =3.0 $cm^2$) intercept?

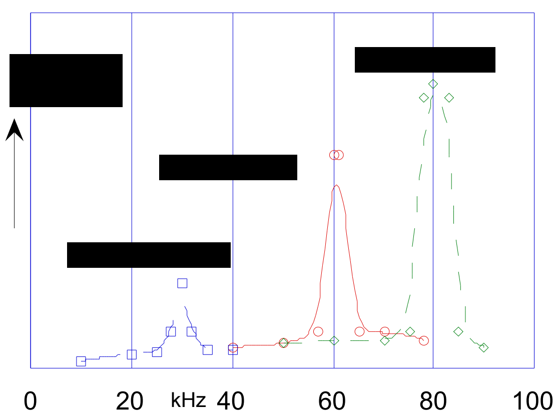
d) What is the sound pressure amplitude at the location of the prey?

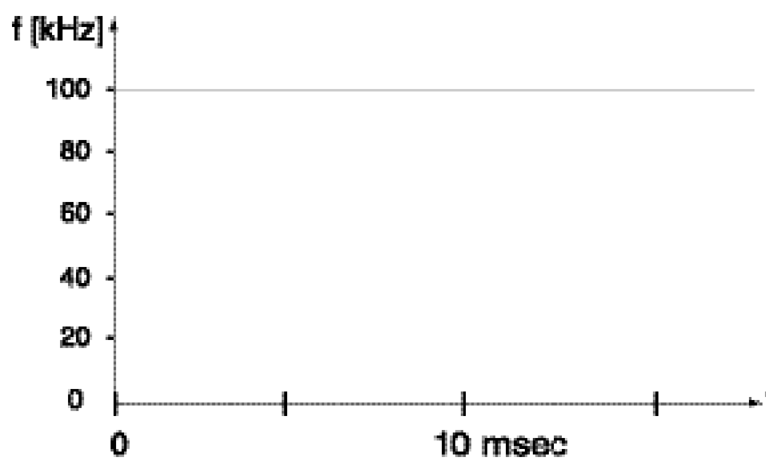
e) A researcher has found that a certain bat can detect the location of its prey using its sonar clicks with an uncertainty Δr ±1.0 cm, (namely it can just distinguish the difference of sound reflection off surfaces at distances $r_1$ and $r_2$ where $r_1$ - $r_2$ = Δr =1.0 cm). Knowing that the bat gets the distance information from the delay time between the two returned sound signals, $S_1$ and $S_2$, estimate the time resolution Δt of the bat's brain.

f) Sketch into the frequency - time diagram a click emitted by the **mustached bat** and the return signal from the moth.

g) Bats can also emit shrieks, tone-like signals, in certain frequency ranges. Sketch into the figure above such a shriek of a **little brown bat**, lasting 12.0 milliseconds.

h) Doppler shifts are due to relative velocities between sender and receiver. How can bats distinguish between the shift due to their own motion and the shift due to the motion of their prey? For instance if a **horseshoe bat**, flying at a speed of 2.0 m/s, is chasing a moth that flies away at a speed of 1.3m/s what is the frequency shift heard by the bat?



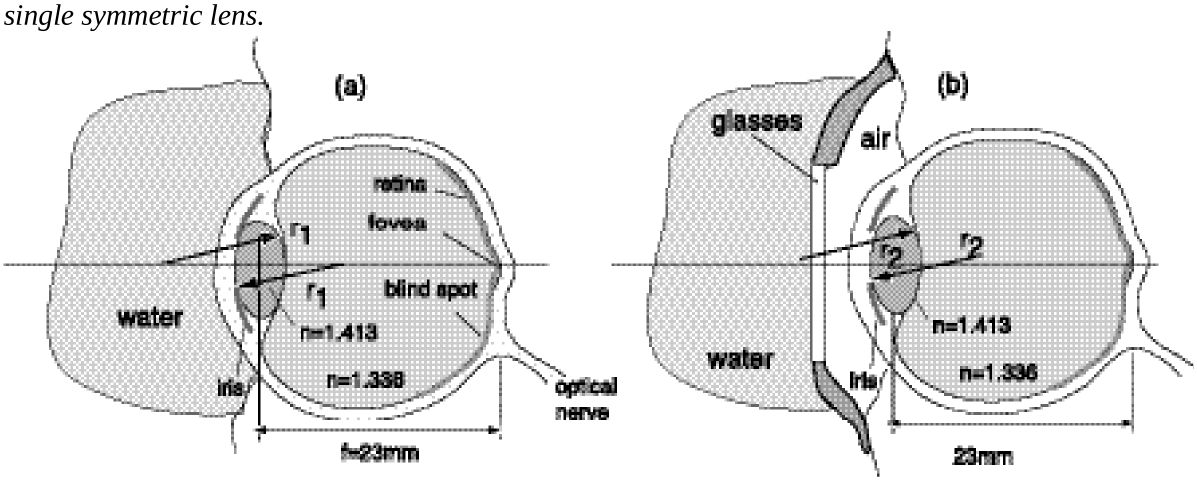



**A6 - Optics**
**Treasure Hunt**

Sally Fairweather wades through shallow water (of depth h=1.00 m) looking for treasures. Suddenly she spots an old silver dollar ( d=2.5 cm) sparkling in the sunlight.

a) How deep does the object appear to be in the water (due to the refraction of light)?
b) When she keeps her eyes very close above the water surface looking at the object, what is the radius of curvature $r_o$ of her eye lenses when her eyes are focussed onto the object?
c) To collect the coin she must bend down so that she can pick it up with her stretched out arm (L=0.75m). But her head gets under water. What is the new radius of curvature $r_1$ of her eye lenses when she focuses onto the object under water , see Fig (a)
d) What would be the radius of curvature $r_2$ had she put on goggles ? Fig (b)?
e) Happy with the find she climbs back onto the beach and stretches out on her bath towel looking into the sky. Suddenly she notices a faint slurry in her field of view of the left eye: Dark and bright lines like the diffraction pattern of an object, probably hair, that lodged itself onto her cornea. She notices that the width of the center streak of this patter has the same width as a branch of a tree nearby. Intrigued she gets up and walks over to the tree. She measures 12 paces to the branch. Her pace length is equal to the width of her 3-feet wide bath towel. Then she holds the coin next to the branch. Coin and branch have the same diameter. What is the diameter of the hair that stuck on her cornea?.

*Assume a standard simplified eye, as shown below with i=23 mm, where all the focussing is accomplished by a single symmetric lens.*



**Part B** **Attempt all parts of this problem**

**The physics of Casey.**

We remember fondly our old golden retriever, Casey who had a body weight of 30 kg.

a) What was her basic metabolic rate in Watt? Express this number in Joule/day. How much dog food (25 kJ /g ) would she have to eat just to support her basic metabolic rate?
$\Gamma$=3.6 $M^{3/4}$ =3.6 30 3/4 = 46,15W . $\Gamma=\Delta Q/(24 \cdot 3600)$; $\Delta Q=3.99\,10^6$ J=$\Delta$m h; h= 25MJ/kg,

$$Dm=\frac{46.15\,J/s\cdot 86400\,s}{2.5\cdot 10^7\,J/kg}=0.16\,kg$$

b) If Casey ran up a flight of stairs 2.8 m high in 2 sec how much mechanical power would her leg muscles generate? P= Mg$\Delta$h/ 2sec=412 W

c) If Casey's leg muscles had an efficiency of 20% how much total metabolic power was generated by Casey as she ran up? P=412W =$\eta\,\Gamma$, $\eta$=0.20, $\Gamma$= 412W/0.20 = 2.060 $\cdot 10^3$ W

d) On a hot summer day Casey kept cool by sticking out her tongue. When she was lying on her favorite spot, not doing any work (basic metabolic rate) how much water would she evaporate in an hour in order to get rid of the heat? $G_o=\frac{L_v[J/kg]Dm[kg]}{Dt}$ , W$\Delta$t=3600sec, $L_v$ =2.26$\cdot 10^6$J/kg

$$Dm=\frac{46.15\,W\cdot 3600\,s}{2.26\cdot 10^6\,J/kg}=73.6\,gH_2O$$

e) Casey often cracked nuts with her back teeth, which were as close to the jaw joint as the chewing muscles. If it takes a force of 300 N to break a nut, how much force could she exert at location 1 with her incisors? What is the cross section area A of her jaw muscle? $F=\frac{4\,cm}{11\,cm}\cdot 300\,N=109\,N$

f) How much blood should Casey pump through her body to support her metabolism when she was resting? What was her blood flow velocity in the aorta if the fluid velocity should stay just below the laminar - turbulent transition? $j=1.5\cdot 10^{-6}\,b\cdot M^{3/4}$ , where b=1. M=. Then $\varphi$=19.2 $10^{-6}$ $m^3$ = $\pi R^2$ u. where u is blood flow velocity and R radius of aorta. Thus (1) $R^2$= $\varphi/\pi$u. Flow should stay laminar, then (2) Re= 2R u / $\nu$ $\leq$.2300. where blood viscosity is $\nu$=4 $10^{-6}$ $m^2$/s. Solve (2) for $R^2 \leq 4600^2\,10^{-12}$/u. Use this to eliminate $R^2$ from (1) and get u$\leq 4600^2\,10^{-12}/\varphi$ , or $u_{aorta} \leq$ 3.5m/s.

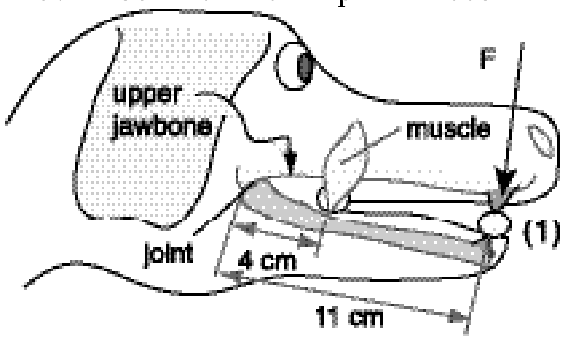
g) Casey's eye was somewhat like your own eye just smaller ( let's assume the eye was exactly 1/2 the size of the human eye, but the rods and cones have the same lateral width $\Delta$=1/400 mm). Suppose she looked at a tennis ball (diameter D=65 mm) at a distance of o = 3m. What was the diameter of the image on the retina?
Image distance of dogs eye i=23mm/2 =11.5mm. From similar triangles find image height
I=D i/ o=65mm 11.5mm/3000mm=0.25mm

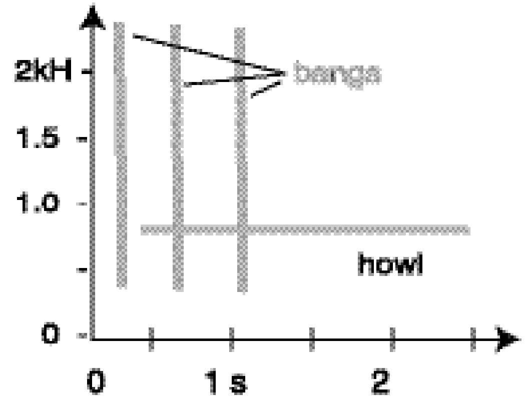
h) How many rods and cones would the image of the ball cover?
Image area A= $\pi$(I/2)2= 0.04.9 $mm^2$ = n a, where the area used up by each pixel is a= $(1/400)^2$ $mm^2$
Then n= A/a = 7790 pixels

i) Casey could hear very faint sounds. She would raise her head when she heard a whisper of sound level ß = 12 dB. What is the pressure amplitude of this sound?

I= $10^{1.2}$ .$10^{-12}$ = 1.56 $10^{-11}$ W/$m^2$. $Dp=\sqrt{2\rho\,vI}=1.18\cdot 10^{-4}\,\frac{N}{m^2}$

j) Casey sometimes banged her tail on a door in order to get in, and sometimes she howled with a clear tone ( say of 880 Hz) for about two seconds.
Sketch the frequency - time traces of these two sounds into the f- time <u>diagram</u>




Latent heat of evaporation $L_V$= 2257 kJ / kg, viscosity of blood $\nu_{bl}$= 4 $\cdot 10^{-6}$ $m^2$/s

## Part C

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

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## Part D poster questions

*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.*

**Poster 1 Roar lions roar**

(sorry Sandy you cannot do this)
Lions stretch their neck when they roar, so that the throat is practically a straight tube. Consider a lion with throat length of L=40cm.
a) What is its basic tone and what is his first harmonic?
b) Assume a lion produces a sound of ß= 40 dB at a distance of 4 km. What sound intensity is that, and what is the pressure amplitude of the sound vibration?
c) If Atmospheric absorption can be neglected, what would be his sound intensity at a distance of 10 m?

**Poster 2 Vulcans**
(sorry Sophy you cannot do this)
Vulcans live on a planet with very lows atmospheric pressure $p_V$= 30 kPa (versus earth $p_{earth}$=101 kPa), consisting of oxygen and nitrogen mixed in the same ratio as ours. They have the same typical weight and look much like humans from the outside, metabolic rate like ours $\Gamma$=b 3.6 $M^{3/4}$ , and have the same heart stroke volume but their heart rate is 4 times our own, and their lungs have adapted to their environment
a)How much air ($m^3$/s) do they have to take in to support their metabolism? *(Question A4 might help you here*
*b)* How large do you think is their lung area? Comment on the number and size of their alveoli.
c) What is the power of their hearts to support their resting metabolic rate ??