McGill University

PHYS 101

(Introduction to Mechanics for the Life Sciences)

FINAL EXAM

December 14, 2007
9:00 AM – noon

Examiner: K.J. Ragan x6518
Associate Examiner: G. Moore x4345

The exam comprises two parts on four pages (including this page): 10 short answer questions, and 6 problems. A formula sheet is attached to the back of the exam. No books or notes of any kind are allowed, except for dictionaries. Calculators are allowed.

Answer **all the short answer questions** with a few words or a few short phrases. For the problems, your grade will be calculated with the **best five problems**. Show your work.

The short answer problems are worth two points each, and the problems are worth 10 points each. Put all answers in the **answer booklets** provided; you may keep this exam.

Good luck !

Short answer questions (answer all): you should not need to do any calculations for these questions, and should answer in **a few words, a few short phrases, or a simple sketch.** In some cases you might find it useful to quote an appropriate formula.

1) [2 pts] Two objects of the same mass move down an inclined plane: a block slides down without friction, and a cylinder rolls down without slipping. Which arrives first, and why?

2) [2 pts] A boy is on the outer edge of a merry-go-round that is spinning frictionlessly. He walks to the inner edge. Does the angular velocity of the system (boy + merry-go-round) increase or decrease, and why?

3) [2 pts] Two untethered (unattached) astronauts on a space walk decide to have a game of catch, lobbing a ball back and forth. Describe what happens as the game progresses. Would it be safest for the astronauts to do this with a ping-pong ball (remember, there's no atmosphere so there's no air friction) or a medicine ball (a medicine ball is a very massive ball)?

4) [2 pts] Explain, in terms of friction and centripetal force, how a lettuce spinner works. (A lettuce spinner is a device into which you put wet lettuce; spinning the lettuce removes the water).

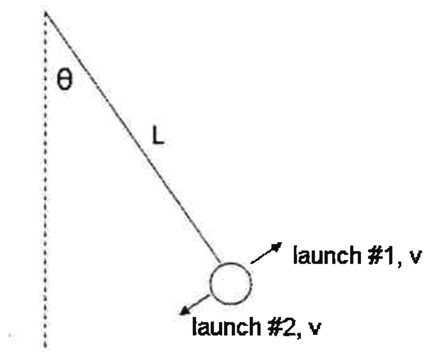
5) [2 pts] A steel ball is dropped onto a concrete floor and rebounds over and over to the original height. Is this simple harmonic motion? Explain why or why not.

6) [2 pts] To convey an impression of power, a car ad claims that "the force of acceleration pushes you back in your seat". Is this a correct description of the physics of the situation? If not, explain briefly.

7) [2 pts] You are looking at a thin soap bubble (a film of soap with air on both sides). The soap appears to be a particular colour, something that you understand as constructive interference of that colour, given the soap's thickness. However, as the soap layer becomes very thin, it looks darker and darker, and appears black just before breaking. The blackness indicates that destructive interference is occurring for all wavelengths. Explain why.

8) [2 pts] You're sitting upright on a beach on a sunny day, and your sunglasses do a good job of blocking the glare from the lake. Will they work as well if you lie down on your side? Explain in a few phrases why, or why not.

9) [2 pts] A pendulum is launched with a speed v from a point that is above its lowest point, as shown in the figure. Which launch – launch 1, upwards, or launch 2, downwards – will result in the largest speed of the pendulum at the bottom of its swing?



10)[2 pts] Draw the free body diagram of a piece of wood that a carpenter is holding against the wall (above the floor) as he prepares to drive a nail into it. The carpenter is pushing <u>horizontally</u>. Label all forces clearly.

Long problems (do five out of six):

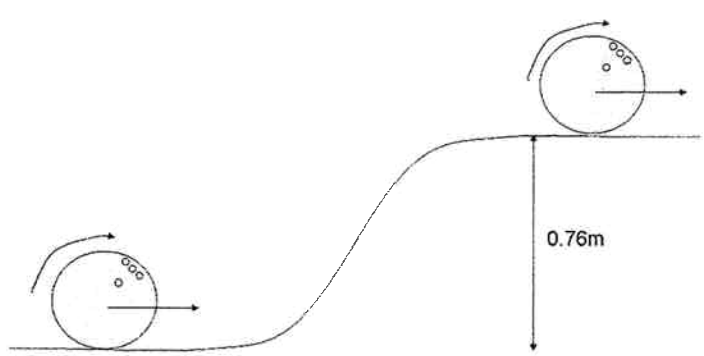
1) [10 pts] A block is attached to a horizontal spring and oscillates back and forth on a frictionless horizontal surface at a frequency of 3.00 Hz, with an amplitude of 5.08×10^{-2} m. At the point where the block has its maximum speed, it splits into two identical (equal-mass) blocks and only one of these remains attached to the spring.

a. What is the amplitude and frequency of the simple harmonic motion of the piece that remains attached to the spring?
b. Write the equation for the displacement x of that piece from that moment onwards, assuming the split happened as the block was moving towards the positive x direction.

2) [10 pts] A small postage stamp is placed in front of a concave mirror (of radius R) such that the image distance equals the object distance.

a. Draw a ray diagram. It does not need to be to scale, but should accurately reflect (no pun intended!) the physics of the situation.
b. Calculate the object distance in terms of the radius of curvature R of the mirror.
c. Calculate the magnification of the mirror. Is the image upright or inverted?

3) [10 pts] A bowling ball on the way back to the ball rack encounters a vertical rise of 0.760 m as shown in the figure. At the bottom of the rise, the translational speed of the ball is 3.50 m/s. Calculate the translational speed of the ball at the top (remember the ball is rolling without slipping in the two cases). The moment of inertia of a solid sphere of mass m and radius r is $I = (2/5)mr^2$.

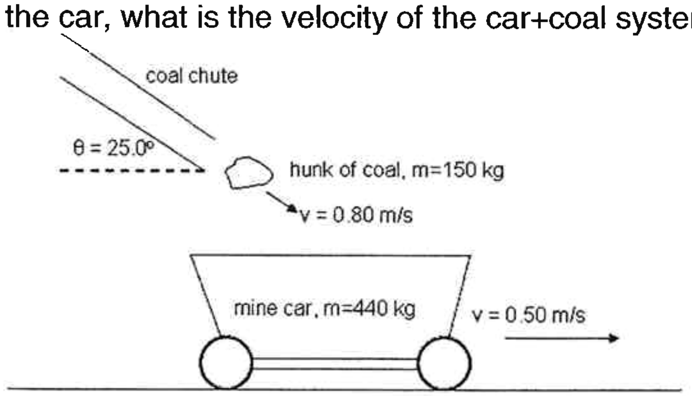


4) [10 pts] A soap film of index of refraction n=1.33 is 465 nm thick and lies on top of a glass plate (index of refraction 1.52). Sunlight (which we can assume is made up of all wavelengths between 380 nm to 750 nm) travels through the air and strikes the soap film perpendicularly. Calculate all wavelengths in this range for which the soap film appears dark.

5) [10 pts] A projectile of mass 0.750 kg is shot straight upwards with an initial speed of 18.0 m/s.

a. How high would it go if there were no air resistance?
b. If the projectile rises to only 11.8 m, what is the magnitude of the average force due to air resistance?
c. If we assume the magnitude of the average force due to air resistance on the descent is the same as that on the ascent (as calculated in part b)), what is the speed of the projectile when it reaches the ground?

6) [10 pts] A mine car of mass 440 kg rolls at a speed of 0.50 m/s on a frictionless horizontal track (see figure). A chunk of coal of mass 150 kg has a speed of 0.80 m/s as it leaves a chute above the car. The angle of the chute is 25.0° from the horizontal. After the coal has come to rest in the car, what is the velocity of the car+coal system?



PHYS 101 Formulae

Vectors are in **bold**

General equations and constants:

Solution to quadratic:	$ax^2 + bx + c = 0 \rightarrow x = (-b \pm \sqrt{(b^2-4ac)})/2a$
Law of cosines:	$\lvert \mathbf{a}+\mathbf{b} \rvert^2 = a^2 + b^2 + 2ab\cos(\Theta)$
Acceleration due to gravity:	$g = 9.8\ m/s^2$
Gravitational constant:	$G = 6.67 \times 10^{-11}\ N\ m^2/kg^2$
Mass of the Earth :	$M_E = 6.0 \times 10^{24}\ kg$
Moment of inertia of a point mass:	$I = mr^2$
Moment of inertia of a sphere:	$I = (2/5)\ mr^2$
Speed of sound in air at sea level:	$v = 343\ m/s$
Speed of light	$c = 3.00 \times 10^8\ m/s$
Threshold intensity of audible sound:	$I_0 = 1.0 \times 10^{-12}\ W/m^2$
Threshold pressure of audible sound:	$p_0 = 3.0 \times 10^{-5}\ Pa$
Index of refraction of water:	$n = 1.33$
Index of refraction of glass:	$n = 1.5$

Motion at constant a:	$\mathbf{v} = \mathbf{v_0} + \mathbf{a}t$
	$x = x_0 + v_0 t + \frac{1}{2} at^2$
	$v^2 = v_0^2 + 2a(x-x_0)$
	$v_{aver} = (v + v_0)/2$
Reference frames:	$\mathbf{v}_{\text{in frame A}} = \mathbf{v}_{\text{in frame B}} + \mathbf{v}_{\text{B in A}}$
Newton's 2nd law:	$\mathbf{F} = m\mathbf{a} = \Delta\mathbf{p}/\Delta t$
Force of friction	$F_{friction} = \mu_{(kinetic,\ static)} F_N$
Centripetal acceleration	$a = v^2/r$
Banked curve, frictionless surface:	$\tan\Theta = v^2/(rg)$
Force of gravity:	$F = G\,(m_1 m_2)/r^2$
Kepler's 3rd law:	$T^2/r^3 = 4\pi^2/(GM)$
Work:	$W = \mathbf{F} \cdot \mathbf{d}$
Kinetic energy:	$KE = \frac{1}{2} mv^2$
Work-energy	$W_{net} = \Delta KE$
Gravitational potential:	$PE_{grav} = mgh$ (near Earth's surface)
Elastic potential energy:	$PE_{spring} = \frac{1}{2} kx^2$
Hooke's law:	$F = -k\,x$
Power:	power = energy/time = $W/t = \mathbf{F} \cdot \mathbf{v}$
Linear momentum	$\mathbf{p} = m\mathbf{v}$

Impulse:	$\Delta p = F\Delta t$
Center of mass:	$x_{CM} = (x_A m_A + x_B m_B + ...)/(m_A + m_B + ...)$
Linear and angular velocity:	$v = r\,\omega$
Angular motion at constant α:	$\omega = \omega_0 + \alpha t$
	$\Theta = \omega_0 t + \frac{1}{2}\alpha t^2$
	$\omega^2 = \omega_0^2 + 2\alpha\Theta$
	$\omega_{aver} = (\omega + \omega_0)/2$
Torque:	$\tau = F_{\perp} r$
Newton's second law for rotation:	$\tau = I\,\alpha$ $\qquad I = \Sigma\, m\, r^2$
Rotational kinetic energy	$KE_{rot} = \frac{1}{2} I\,\omega^2$
Rotational (angular) momentum:	$L = I\omega$
Frequency/period relationship:	$f = 1/T$
Period of SHM (spring):	$T = 2\pi\,\surd(m/k)$
Speed of object undergoing SHM:	$v = \pm v_{max}\,\surd(1-x^2/A^2)$ $\qquad v_{max} = 2\pi A/T$
Maximum acceleration:	$a_{max} = (k/m)\,A$
Sinusoidal motion of SHM:	$x = A\sin(2\pi\,t/T) = A\sin(\omega t)$
Pendulum SHM:	$T = 2\pi\surd(L/g)$
Wave speed, wavelength, frequency:	$v = \lambda\, f$
Speed of wave on a cord:	$v = \surd(F_T/[m/L])$
Intensity of wave:	$I = 2\pi^2 v\rho\, f^2\, A^2$
	$I = p^2/(2v\rho)$
Standing waves on string:	$\lambda_n = 2L/n$
Reflection:	$\Theta_{inc} = \Theta_{ref}$
Refraction (waves):	$v_1 \sin(\Theta_2) = v_2 \sin(\Theta_1)$
Sound intensity (decibels)	$\beta = 10\log(I/I_0) = 20\log(P/P_0)$
Harmonics of open tubes:	$f_n = nf_1 = n\,(v/2L)$ $\qquad$ for n=1,2,3...
Harmonics of closed tubes:	$f_n = n\,f_1 = n\,v/4L$ $\qquad$ for n=1,3,5... (only odd harmonics)
Beat frequency:	$f_b = \lvert f_1 - f_2 \rvert$
Doppler shift:	$f' = f\,[1/\{1 \pm (v_{source}/v_{wave})\}]$
	(source moving away from(+)/towards(-) observer)
	$f' = f\,[1 \pm (v_{obs}/v_{wave})]$
	(observer moving towards(+)/away from(-) source)
Focal length of spherical mirror:	$f = r/2$
Mirror and lens equation:	$1/f = 1/d_o + 1/d_i$

Magnification:	$m = h_i/h_o = -d_i/d_o$	
Index of refraction:	$n = c/v_{light}$	
Snell's law of refraction:	$n_1 \sin(\Theta_1) = n_2 \sin(\Theta_2)$	
Critical angle for TIR:	$\sin(\Theta_c) = n_2/n_1$	
Lensmaker's equation:	$1/f = (n - 1)(1/R_1 + 1/R_2)$	
Lens power:	$P = 1/f$	
Diffraction around object:	$\Theta_{diff} \approx \lambda/D$	
Constructive interference (2-slit):	$d \sin(\Theta) = m\lambda$	m = 0,1,2...
Destructive interference:	$d \sin(\Theta) = (m + \frac{1}{2})\lambda$	m = 0,1,2...
Single slit diffraction minima:	$D \sin(\Theta) = m\lambda$	m = 1,2,3... (not 0!)
Intensity reduction by polarizer:	$I = I_o \cos^2(\Theta)$	polarized light
	$I = \frac{1}{2} I_o$	unpolarized light
Brewster's angle	$\tan(\Theta_p) = n_2/n_1$	
Magnification of magnifying glass:	$M = N/f$	eye focused at ∞
	$M = N/f + 1$	eye focused at near point
Magnification of telescope:	$M = -fo/fe$	
Diffraction spot size/resolution:	$\Theta = 1.22\lambda/D$	