THE UNIVERSITY OF SYDNEY

PHYS 1002
PHYSICS 1 (FUNDAMENTALS)

JUNE 2011

Time allowed: THREE Hours

MARKS FOR QUESTIONS ARE AS INDICATED
TOTAL: 90 MARKS

INSTRUCTIONS

• All questions are to be answered.
• Use a separate answer book for section A and section B.
• All answers should include explanations in terms of physical principles.

DATA

Density of fresh water at 20 °C and 1 atm $\rho = 1.000 \times 10^3$ kg.m\(^{-3}\)
Density of sea water at 20 °C and 1 atm $\rho = 1.03 \times 10^3$ kg.m\(^{-3}\)
Atmospheric air pressure $P = 1.013 \times 10^5$ Pa
Free fall acceleration at Earth's surface $g = 9.80$ m.s\(^{-2}\)
Speed of light in vacuum $c = 3.00 \times 10^8$ m.s\(^{-1}\)$
SECTION A

Question 1
A large cylindrical beaker is one-third filled with water. An equal volume of liquid mercury is then poured into the beaker. (Water and mercury are ‘immiscible’, i.e., one does not mix with the other.)

(a) Sketch the system, showing the beaker, water and mercury after completion of the pouring. Explain briefly why the system is as you show it.

(b) If the total depth of liquid (water + mercury) in the beaker is 0.360 m, find the total pressure (including the effect of the atmosphere) just above the bottom of the beaker.

(c) A small steel block is now dropped (carefully) into the beaker. Sketch the system after the steel block has come to rest. Explain briefly why the steel block is located where you show it.

Densities:

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg m(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure water</td>
<td>1.00 \times 10^3</td>
</tr>
<tr>
<td>Mercury</td>
<td>13.6 \times 10^3</td>
</tr>
<tr>
<td>Steel</td>
<td>7.8 \times 10^3</td>
</tr>
</tbody>
</table>

(5 marks)
Question 2

The bacterium *Escherichia coli* (or *E. coli*), is a single-celled organism that lives in the gut of healthy humans and animals. When grown in a uniform medium rich in salts and amino acids, it swims along zig-zag paths at a constant speed. The points are not equally spaced in time. The figure below shows the positions of an *E. coli* bacterium as it moves from point A to point J. Each segment of the motion can be identified by two letters, such as segment (BC).

![Diagram of a bacterium](image)

Write your answer as segments expressed as (BC) etc.

(a) During which segments, if any, does the bacterium travel the same distance?
(b) During which segments, if any, does the bacterium have the same displacement (relative to its position at the start of the segment)?
(c) During which segments, if any, does the bacterium have the same speed?
(d) During which segments, if any, does the bacterium have the same velocity?
(e) On which segment, or segments, does the bacterium spend the least time?

(5 marks)
Question 3

A woman is attempting to balance a see-saw with her identical twin boys (see diagram below, not drawn to scale). She has a mass of 60 kg, and sits 1.0 m from the pivot point. The two boys sit 1.5 m and 1.2 m from the pivot point and have identical mass.

(a) Draw a diagram for the see-saw, showing the location and direction of all the forces acting. All three people can be treated as point masses.

(b) For each force you identified in part (a) write an expression for the torque around the pivot point due to that force.

(c) If the see-saw balances, what are the masses of the children?

(5 marks)
Question 4

A simplified Newton’s cradle demonstration consists of two balls of equal mass. The balls are suspended from a frame so that their surfaces just touch (see diagram below).

With reference to the concepts of conservation of momentum, mechanical energy and total energy, answer the questions about the two cases described below.

Case 1: The balls are made of steel and when Ball A is drawn back and released, it makes an elastic collision with Ball B.

(a) Describe the motion of the two balls before and after the collision.

(b) Which conservation laws are applicable in part (a) and explain why (or why not they apply)?

Case 2: The balls are made of soft clay and the collision is completely inelastic.

(c) Describe the motion of the two balls before and after the collision.

(d) Which conservation laws are applicable in part (c) and explain why (or why not they apply)?

(5 marks)
Question 5

The graph below shows a particle executing simple harmonic motion in the x-direction.

(a) What is the amplitude of the motion?

(b) What is the frequency of the motion?

(c) Consider two particles oscillating in simple harmonic motion. Particle 1 is oscillating with a motion of amplitude $A$ and frequency of $f$. Particle 2 is oscillating also with an amplitude $A$ but with a frequency of $2f$. How does the maximum acceleration experienced by Particle 2 compare with that experienced by Particle 1?

(d) Explain why the equation
\[ y = A \sin(\omega t) \]  
(1)
describes a particle executing simple harmonic motion but the equation
\[ y = A \sin(\omega t) + A \sin(2\omega t) \]  
(2)
does not.

Hint: Equation (2) describes a motion which is the sum of two different simple harmonic motions. Consider the acceleration of the particle and compare it with that expected for simple harmonic motion.

(5 marks)
**Question 6**

Helen and Greg are two instrument builders who are competing to see whose instrument can play the note with lowest frequency. Helen builds a giant saxophone of length 4.0 m, which acts like an open pipe. Greg builds a giant clarinet of length 4.0 m, which acts like a closed pipe. The speed of sound in air is 344 m.s\(^{-1}\).

(a) Draw a sketch showing the fundamental mode for Helen’s saxophone.

(b) Draw a sketch showing the fundamental mode for Greg’s clarinet.

(c) Which builder, Helen or Greg, wins the competition?

(d) Calculate the frequency of the lowest note for the winning instrument.

(5 marks)
SECTION B
(Please use a separate book for this section.)

Question 7
A watertight shipping container of dimensions $12.0 \text{ m} \times 3.00 \text{ m} \times 3.00 \text{ m}$ is washed off the deck of a cargo ship and falls into the ocean. The mass of the container with its contents is $2.20 \times 10^4 \text{ kg}$.

(a) Calculate the average density of the container with its contents.

(b) Explain briefly why the container will float.

(c) Calculate the fraction of the container’s volume that is below the water surface while it is floating. Be sure to explain your reasoning.

(d) During a storm the container is tossed violently and at a certain moment it is fully submerged (but remains watertight).

(i) Draw a diagram showing the forces acting on the container at this moment. Use the length of vectors to indicate approximately the relative magnitude of the forces. (Ignore forces due to motion of the water around the container).

(ii) Calculate the net (resultant) force on the container and briefly describe the effect it will have.

Hint: Density of sea-water: $1.03 \times 10^3 \text{ kg.m}^{-3}$

(10 marks)
Question 8

A “rocket” car (car 1) is launched along a straight track at time \( t = 0.0 \text{s} \). It moves with constant acceleration of \( a_1 = 2.0 \text{m.s}^{-2} \). At a time \( t = 2.0 \text{s} \), a second car (car 2) is launched along a parallel track from the same starting point, with constant acceleration of \( a_2 = 8.0 \text{m.s}^{-2} \).

(a) On a single graph, plot lines representing velocity versus time for the motion of the two cars for \( 0 \leq t \leq 4 \text{s} \)

(b) What is the significance of the point at which the two lines intersect?

(c) Calculate the value of time at which the lines intersect.

(d) Write an equation for the distance \( s_1 \) travelled by car 1 as a function of time \( t \) after it is launched. Substitute your value for \( a_1 \) so that your equation only involves the symbol \( t \).

(e) Write an equation for the distance \( s_2 \) travelled by car 2 as a function of time \( t \) after it is launched. Substitute your value for \( a_2 \) so that your equation only involves the symbol \( t \).

(f) Write an equation for the separation \( s_1 - s_2 \) of the cars as a function of time \( t \) after both have been launched.

(g) When both cars have travelled equal distances their separation must be zero. Set \( s_1 - s_2 = 0 \) in your answer to part (f) and obtain the value of \( t \) for which this is true. The hint at the end of the question may help with your solution of this quadratic equation. Alternatively, substitute some values for \( t \) into your equation from part (f) to help find the solution.

Hint: The two possible solutions of a quadratic equation \( ax^2 + bx + c = 0 \) are given by:

\[
x_1 = \frac{-b + \sqrt{b^2 - 4ac}}{2a}
\]

\[
x_2 = \frac{-b - \sqrt{b^2 - 4ac}}{2a}
\]

(10 marks)
Question 9
A 0.060 kg arrow is moving vertically upward at a speed of 50 m/s just as it hits a block of wood of mass 5.0 kg. The arrow stops in the block and the block is free to move vertically.

(a) What is the kinetic energy of the arrow just before the collision?
(b) What is the momentum of the arrow just before the collision?
(c) What is the momentum of the block (with arrow embedded in it) just after the collision?
(d) What is the velocity of the block just after the collision?
(e) How much energy was lost in the collision?
(f) How high does the block rise above its initial position?

(10 marks)
Question 10

Jane is leading her weekend small car race approaching the final bend, which is a perfectly flat circular right-hand bend of radius 30.0 m. She is being closely pursued by Chris in an identical car. Both are travelling at a speed of 13.9 m.s\(^{-1}\). Chris begins to brake to take the bend, reducing his speed to 11.1 m.s\(^{-1}\). Jane, in the heat of the battle, continues at her original speed of 13.9 m.s\(^{-1}\). Air resistance is negligible.

(a) If Jane and Chris negotiate the bend successfully, then by Newton’s Laws there must be a force acting on their cars to make them turn, since they change their velocity vectors (accelerate) as they go round. What produces the force in this case?

(b) Calculate the magnitude of Jane’s acceleration as she attempts to round the bend.

(c) Show that the maximum speed at which Jane or Chris can drive around the bend without slipping is given by

\[ v_{\text{max}} = \sqrt{rg \mu_s} \]

where \( r \) is the radius of the bend, \( g \) is the magnitude of the acceleration due to gravity, and \( \mu_s \) is the coefficient of static friction between the tyres of either car and the road.

(d) Suppose that \( \mu_s = 0.80 \). Based on the formula you derived in part (c), who should win the race, and why?

(e) Both cars have mass 200 kg. Jane’s mass is 50 kg and Chris’s is 75 kg. Would your answer be the same if their masses were the other way around? Justify your answer.

(10 marks)
Question 11

(a) A thrill-seeking bungee jumper of mass $m$ steps off a bridge and free falls. The jumper is attached to a bungee cord of natural length $L$ and after she has fallen a distance $L$ the cord then acts like a spring with spring constant $k$. Assuming Hooke’s Law is valid and using the Principle of Conservation of Energy, show that the maximum extension of the cord $h$ when the jumper comes to rest momentarily at the bottom of the fall can be found by solving the quadratic equation below (where $g$ is the acceleration due to gravity).

$$\frac{1}{2} k h^2 - m g h - m g L = 0$$

(b) A system is acted upon by a sinusoidal driving force that causes the system to vibrate. The frequency of the driving force is $f_d$ and the natural frequency of the system is $f_0$. The graph below shows the response of the system when $f_d / f_0 = 0.5$.

(i) Draw a graph showing a possible response of the system when $f_d / f_0 = 1$.

(ii) Draw a graph showing a possible response of the system when $f_d / f_0 = 2$.

(The scales on your diagrams should be the same as shown on the diagram above. Your diagrams should show approximately the correct periods for the oscillations.)

(iii) How do your graphs relate to the enormous damage done to some buildings during an earthquake?

(10 marks)
Question 12

Richard wishes to test the Doppler effect for sound waves. To do so, he attaches a sound wave generator to the arm of a large centrifuge (normally used to train astronauts and pilots to withstand high “g” forces) as shown in the diagram below. The distance between the centre of rotation and the sound generator is 10.0 m. The sound generator produces a single tone of frequency 2000 Hz and the centrifuge is set to make a complete revolution once every 2.0 s. The speed of sound in air is 344 m s\(^{-1}\).

A sound detector is placed at rest at a large horizontal distance (much larger than the size of the centrifuge) to the right of the centrifuge and is used to measure the frequency and wavelength of the sound produced by the generator.

![Diagram of centrifuge and sound generator](image)

(a) Calculate the tangential speed of the sound generator as the centrifuge rotates.
(b) Calculate the wavelength of the sound measured by the detector before the centrifuge begins to rotate.
(c) The detector finds that the frequency of the sound wave is changing as the centrifuge rotates. Explain why this occurs.
(d) Describe how the detected sound frequency changes as the centrifuge rotates, indicating at which point(s) (numbered 1, 2, 3, 4 in the above diagram) the frequency is highest and at which point(s) it is lowest.
(e) What is the value of the highest frequency measured by the detector?
(f) What is the wavelength of the sound measured by the detector when the frequency is highest?

(10 marks)

THIS IS THE END OF YOUR QUESTIONS