# University of Toronto

# 2001-2002 Physics Olympiad Preparation Program

## Problem Set 2: Mechanics

*Due Monday 17 December 2001*

***(Note small extension to due date!)***

Welcome back.

- This and the next 4 problem sets each concentrate on different areas of physics, but this does not mean that you do not need to use a broad range of physics. For example, every question on this problem set requires knowledge of mechanics[1], but knowledge of mechanics alone may not be enough to solve every problem.
- Each problem set has an experimental question. They typically require a few common items, but you should look at them early in case you have to find something you don't immediately have. Your Physics teacher may be able to help.
- If you can't do all of a question, do the parts you can do.
- Unless otherwise specified, assume everything takes place on the earth's surface and gravity points down in all our diagrams.
- We often provide links to websites, but the problems do not require any information from these websites. Often the links are just for fun.

### 1) Salty log!

Salt water is denser than fresh water, and in the ocean you will sometimes find a sharp vertical discontinuity in salinity (known as a "halocline") between fresher water on top and saltier water underneath. This often happens near coasts where fresh water runs into the sea or where glaciers or sea ice are melting. Variations in seawater salinity and temperature drive the circulation of deep ocean waters[2] and have a major impact on climate.

Consider a log washed down a river and out to sea. Eventually the log becomes saturated with water and it starts to sink, but if it reaches a halocline it may float on the boundary. If the log has a uniform density $\rho_L$, and the (assumed) uniform densities of the surface and deep water are $\rho_S$ and $\rho_D$, what fraction of the volume, $V$, of the log will be above the halocline in the fresher water.

*[Isamu]*

---

1 At least "mechanics" as defined by us.

2 http://www.oceansonline.com/watermasses.htm

## 2) Don't leave me!

(a) Show that the Sun's gravitational force on the Moon is more than twice the force of the Earth on the Moon. (The distance from the moon to the earth is about 400000 km.)

(b) So why doesn't the Sun pull the Moon away from the Earth?

*[David]*

## 3) Singing in the rain!

If you are suddenly caught out in the rain, is it better to run or walk to the nearest shelter?

(a) First consider the case where there is no wind and you have no umbrella. Assume it is a distance $L$ to the shelter, the raindrops are falling with a constant velocity $u$, and the rain is falling at a constant rate of $n$ mm/hour. Calculate how wet will you get (*i.e.* how mach rain will hit you) if you walk with a constant speed $v$ to the shelter. What speed, $v$, should you walk or run to minimize how wet you get? (Your maximum speed is $v_{max}$.)

(b) What is your answer if you have an umbrella?

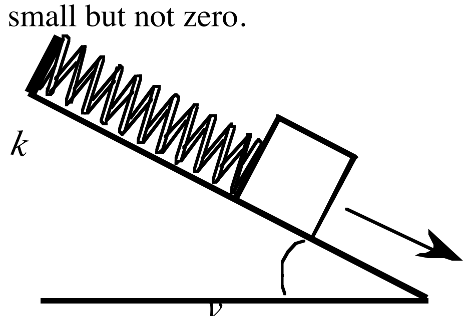
(c) What is your answer if you have an umbrella and the rain is failing at an angle $\theta$ in to the direction you are walking? *i.e.* $\theta$=0° is the rain falling vertically, $\theta$=90° is the rain blowing horizontally into your face, $\theta$=–90° is the rain blowing horizontally into your back. (Assume the vertical component of the velocity of the rain is still $u$.)

*Hints*: Simplify a person as a rectangular cube. An umbrella prevents water from hitting the top of the cube, but not the front, back, or sides. By "rate", I mean that after one hour an open container left out in the rain will have a layer of water $n$ mm deep.

*[Yaser]*

## 4) Sproing!

A block of mass $m$ sliding on a ramp is connected to a spring that has a negligible mass and a force constant of $k$, as shown in the figure. The spring is unstretched when the system is as shown in the figure, the block has an initial velocity $v$ down the ramp, and there is friction between the incline and the block. The static and kinetic coefficients of friction are $\mu_s$ and $\mu_k$; you can assume the friction is small but not zero.




(a) Estimate how much smaller the kinetic energy of the block will be the next time it passes through the initial point. $\alpha$

(b) About how often is the block's velocity zero? (*i.e.* What is the frequency that $v$=0?)

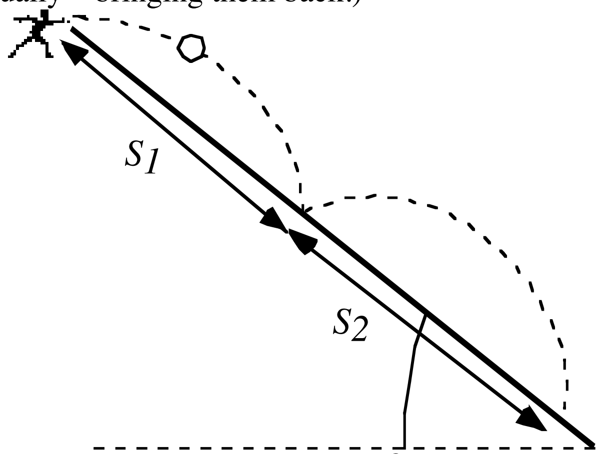
(c) Plot qualitatively the position of the block as a function of time until it permanently stops.

(d) Where is it more likely for the block to permanently stop: at a point higher or at a point lower than the initial point (where the spring is unstretched)? Explain your answer.

*[Isamu]*

## 5) Fun before television!

Professor Bailey lived on a steep hill when he was a kid, and he and his friends used to throw balls down the hill to try to get them into the woods at the bottom with only one bounce. (Fortunately they had some helpful dogs who thought it was great fun to do the hard part of finding the balls and – usually – bringing them back.)




If you are standing on top of a smooth linear hill with a slope of $\tan\theta$ and throw a ball out horizontally with an initial velocity $v$,

(a) how far down the hill, $S_1$, will the ball hit on its first bounce?

(b) What is the ratio, $S_2/S_1$, of the distance ($S_2$) travelled by the ball on its second bounce over the distance ($S_1$) travelled on the first bounce?

*Hints*: Assume the bounces are perfectly elastic. Ignore air resistance.

*[Alex]*

## 6) Soup's on! Roll over Galileo!

Dr. Zed loves science, but even he sometimes gets misquoted in the press. As reported in the Summer 1996 issue of the popular Canadian children's magazine "Chickadee"[3], Dr. Zed likes to race empty and full soup cans against each other down a ramp. The magazine said that full cans always won because they were heavier.

(a) Is it true that full cans roll faster than empty cans? Was the magazine's explanation correct?

*Note*: The empty and full cans in each race are identical except – Duh! – the empty cans are empty and the full cans are full, and both the top and bottom of the empty cans are removed by a traditional can opener that leaves the rims on the can. The ramp is not too steep, so the cans roll on the rims without slipping. Dr. Zed used condensed cream soup so the contents of the full cans are jelly-like and act more or less like a solid as long as they are not subject to too high a stress. Dr. Zed likes soup a lot, so he has a big supply of empty and full soup cans. He also has cans full of all sorts of other stuff – beans, tomato paste, pumpkin pie filling – if he wants some variety for his can races or for his dinner.

[3] http://www.owlkids.com/

(b) What is the relative acceleration, $a_{full}/a_{empty}$, of the two cans?
   i) Measure it experimentally. (Explain your methods and present your data.)
   ii) Calculate it theoretically.
   iii) Discuss any differences and give possible qualitative explanations for any discrepancies (larger than your uncertainties) between your experimental data and your theoretical calculation.

(c) What happens if you race a can of condensed Cream of Mushroom (or any other soup which is a non-fluid jelly in the can) against the same size can of chicken or vegetable broth (or consommé or any other soup with a water-like consistency in the can)?
   i) Which can is first? What is the experimentally observed relative acceleration, $a_{cream}/a_{broth}$, of the two cans?
   ii) Give a qualitative theoretical explanation for your results.

*Hints*: Measure the relative accelerations either by timing each can separately or by racing them and seeing where the second can is when the first can reaches the bottom – whatever works best for you. Many cheap digital wristwatches have stopwatch functions. The second method works best if you have two people. For a ramp I just used a shelf propped on some books. Don't forget to tell us any possibly relevant experimental parameters, *e.g*. the size of the cans you used and the slope and length of your ramp.

*[David]*

## **POPBits™** – Possibly useful bits of information

### Constants and units[4,5]

| | | |
|---|---|---|
| astronomical unit (mean earth-sun distance) | au | 149 597 870 660±20 m |
| Earth mass | $M_\oplus$ | $(5.974\pm0.009)\times10^{24}$ kg |
| Newtonian gravitational constant | $G_N$ | $(6.673\pm0.010)\times10^{-11}$ m$^3$/kg/s$^2$ |
| Solar mass | $M_\odot$ | $(1.98892 \pm 0.00025)\times10^{30}$kg |
| standard acceleration of gravity at the earth's surface | $g$ | 9.80665 m/s$^2$ |
| tropical year (2001) | yr | 31556925.2 s |

### David's Maxim of the Month

"A measurement without an uncertainty[6] is just a number;
a measurement with an uncertainty is data."

### Great excuse for a party

Nobel Prize awards[7] (Eric Cornell, Wolfgang Ketterle, Carl Wieman) December 10

---

4 http://physics.nist.gov/cuu/Constants/index.html
5 http://pdg.lbl.gov/2000/contents_sports.html
6 Also known as an "error bar".
7 http://www.nobel.se/physics/laureates/2001/index.html