2001-2002 Physics Olympiad Preparation Program

– University of Toronto –

Problem Set 1: General

Due 9 November 2001

Since this is the first problem set, a few comments before starting:

- If you want to know what kind of physics you might need to solve these problems, look at the Physics Olympiad syllabus at http://www.jyu.fi/ipho/syllabus.html. You don't need to know the syllabus by heart to do the problems, but you do need to be able to recognize what you need to know so you can look it up.
- Don't forget to look at the information given in the POPBits™ section at the end of the problem set, it sometimes has information helpful or necessary for particular problems.
- Pay attention to words like "estimate" or "about". They indicate that the expected answer is not exact because either the input data is not precisely known or because approximations or simplifying assumptions are necessary. Much of real physics is learning how to turn insoluble exact problems into soluble approximations.
- "*Nothing ventured, nothing gained*": Whether you finish a problem or not, please make sure your reasoning and analysis are clear. If you write down nothing, it is easy for us to mark – we just give you zero – but pretty boring. Your basic ideas may be right even if you make a mistake or get stuck.
- Now, on with the show!

1) Let the sun shine in!

Hold a small, flat, square mirror toward the sun and send the reflected light onto a wall. Describe how the shape of the bright spot on wall changes as you move the mirror closer to and farther from the wall. What information about the sun can you obtain with this experiment? Write us your measured value and its error.

(*Hints*: I made my mirror by masking a small round mirror with masking tape and paper so that only a 0.5 cm square was exposed; this way you can also easily experiment with different size or shape mirrors by just changing the tape. The mirror does not have to be an exact square, but it does have to be flat, so don't use a mirror which magnifies or reduces, as do many round makeup or hand mirrors. If it is more convenient, you can leave the mirror fixed and look at the reflection on something like a piece of flat cardboard which you move closer to and farther from the mirror.)

[Yaser]

2) Ping-Pong!

A ball will bounce back from a wall with the same speed it hits, if the collision is elastic. What happens if the ball (which is moving with a speed v) hits a "wall" (e.g. a table tennis paddle) that is moving (with a speed u) toward the ball?

(a) What is the velocity of the ball after it bounces back from the wall?
(*Hint*: Think of a frame in which the speed is the same before and after the bounce.)

(b) What is the change in the kinetic energy of the ball if its mass is m?

(c) Try to show that your answer to part (b) is equal to the work done by the wall on the ball. (*Hint*: Assuming the duration of the collision is ΔT, find the force exerted on the ball and its displacement.)

[Yaser]

3) Don't break the window!

You have a ball of mass m attached to a massless string. The maximum tension the string can handle before breaking is T. (What we are actually talking about is a yo-yo that has been left outside until its string starts to rot, but we have translated this into "textbook physics".)

(a) If you hold one end of the string at a height h above the ground, what is the maximum length the string can have so that you can still swing the ball in circles around you without the ball touching the ground or the string breaking?

(b) If you do swing it around in circles slightly too hard and the string breaks, for what length string will the ball fly the longest horizontal distance before hitting the ground?

[Alex]

4) Cowabunga!

First a well known joke: Farmer Smith was not satisfied with the yield of his milk cows, so he decided to called in an animal psychologist, an engineer and a physicist to try to improve matters. All three inspected the farm and the cows and made their recommendations. The animal psychologist went first, "If you paint the milking shed green the cows will be happier and happy cows will give more milk." Then came the turn of the engineer. "If you narrow the milking stalls by 10 centimeters you will be able to add an extra stall and thus be able to milk an extra cow in the same time." Farmer Smith was very happy so far, now it came to the turn of the physicist. She got out a black board, drew a circle and said: "First, we assume a spherical cow."

(a) Estimate the capacitance of a cow.
(*Hint*: To help any city-slickers, I'll point out that a typical run-of-the-mill Holstein[1] dairy cow weighs about 700kg and is more or less neutrally buoyant in water.)

(b) Estimate the resistance of a cow.
(*Hints*: People and cows have similar resistivity.
Sometimes different approximations are necessary for different parts of a problem.)

(c) When a cow walks across a carpet in winter, it can easily charge itself up to 10KV, and it can get a nasty shock if its nose touches a doorknob. Estimate the peak power in such a shock.
(*Hint*: The total resistance of a mammal in an electrical circuit is normally dominated by

[1] http://www.holstein.ca/

skin/contact resistance which can be quite variable, but cows tend to lick their noses which keeps the skin conductivity up, so let's ignore the skin/contact resistance.)

[David]

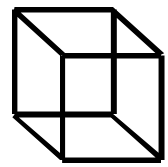
5) Symmetry Cubed!

Here's is a great project for your art class: an electrified hanging mobile made from wire models of the 5 platonic solids.

Consider a wire tetrahedron where each edge has a resistance R.

(a) What is the resistance between any two corners?

What if we replace the tetrahedron with a cube?



(b) What is the resistance between two opposite corners (*e.g.* AD)?

(c) What is the resistance between two diagonally opposite corners on the same side (e.g. AC)?

(d) What is the resistance between two adjacent corners (*e.g.* AB)?

We'll leave calculating the resistance of the various vertices of the octahedron, the dodecahedron, and the icosahedron for your own amusement.

[Alex]

6) Is it hot enough for you?

The Mars Pathfinder mission's Sojourner rover[1] carried 3 small radioactive plutonium heaters to keep its electronics warm. How warm would your radioactivity keep you?

The two largest sources of natural radioactivity in your body are the radioactive isotopes Carbon-14 and Potassium-40. (Carbon-14 is continually produced in the earth's atmosphere by cosmic rays, while the Potassium-40 is part of the primordial composition of the solar system.) About 10^{-12} of the carbon in your body is Carbon-14, and 0.0117% by weight of all potassium is Potassium-40. The decay of a Carbon-14 atom releases an energy of 0.16×10^{6}eV, while the decay of a Potassium-40 atom releases 1.3×10^{6}eV. Both these decays are beta decays, so on average about half the energy released in a decay is carried out of your body by a neutrino, but the other half of the energy is deposited in your body as ionizing radiation. A typical human is about 19% carbon by weight, and about 0.3% potassium,

(a) What is the total activity (i.e. decays per second) of the Carbon and Potassium in your body?

(b) What is the total power (in Watts) deposited in your body by these decays?

(c) If you were put into suspended animation and fired into interstellar space, what would your equilibrium surface temperature be if your internal Carbon-14 and Potassium-40 were the only source of heat keeping your body warm?

[David]

[1] http://mpfwww.jpl.nasa.gov/MPF/index1.html

POPBits™ – Possibly useful bits of information

Constants and units[1,2]

astronomical unit (mean earth-sun distance)	au	149 597 870 660±20 m
atomic mass unit: (mass ^{12}C atom)/12	u	$(1.66053873\pm0.00000013)\times10^{-27}$ kg
elementary (*i.e.* electron) charge	e	$(1.602176462\pm0.000000063)\times10^{-19}$ C
electron volt	eV	$(1.602176462\pm0.000000063)\times10^{-19}$ J
Newtonian gravitational constant	G_N	$(6.673\pm0.010)\times10^{-11}$ m^3/kg/s^2
solar luminosity	$L_\odot$	$(3.846 \pm 0.008)\times10^{26}$W
speed of light in vacuum	c	299 792 458 m/s
standard acceleration of gravity at the earth's surface	g	9.80665 m/s^2
Stephan-Boltzmann radiation constant	σ	$(5.670400\pm0.000040)\times10^{-8}$ W/m^2/K^4
tropical year (2001)	yr	31556925.2 s

Radioactive half-lives of some isotopes[3]

^{14}C	(Carbon-14)	5730±40 years
^{40}K	(Potassium-40)	$1.277\pm0.001 \times 10^9$ years
^{238}Pu	(Plutonium-238)	87.7±0.1 years

Resistivity of human tissue[4]

blood	1.7 Ω·m
bones	160 Ω·m
fat	27 Ω·m
muscle	7.0 Ω·m
nerve	2.5 Ω·m

Great excuse for a party

Birthday of Marie Curie[5] (1867) and Lise Meitner[6] (1878) November 7

---

1 http://physics.nist.gov/cuu/Constants/index.html
2 http://pdg.lbl.gov/2000/contents_sports.html
3 http://ie.lbl.gov/education/isotopes.htm
4 http://www.acusd.edu/~mmorse/BMES2000.shtml
5 http://www.mariecurie.org/mariecurie
6 http://www.users.bigpond.com/Sinclair/fission/LiseMeitner.html