2000-2001 Physics Olympiad Preparation Program

— University of Toronto —

Problem Set 1: General

Due October 30, 2000

1) The path of least resistance (...and highest voltage)

You are given 32 identical 3-volt batteries, each of which has an internal resistance 2 ohms (i.e., even if you short-circuit them with a wire you still have 2 ohms appearing in such a circuit). How can you connect all these batteries together so as to get *highest possible current* through a 4-ohm resistor?

[HINT: Think of the batteries set up in n rows and m columns...] *[Yaser]*

2) The last straw...

a) When you suck on a straw, you create a partial vacuum in your mouth. If a person could make a partial vacuum in their mouth equal to 50% of atmospheric pressure, what's the farthest possible vertical distance above their drink of water?

b) Is it reasonable that your lungs might produce a vacuum 50% that of the atmosphere, by inhaling? What else is at work?

c) Does the size of the straw (its diameter) have any effect on the maximum height?

To answer parts b) and c) it is suggested that you test the effects on height using different-sized straws. Once you have collected the data you can determine the approximate pressure — this is the *empirical* approach.

Materials:
– a bucket or pitcher of water
– a few ~1.5 m lengths of plastic tubing of different diameters (Canadian Tire stores sell this, for example)
– a measuring tape

<u>The plan</u> — If you suck up water from the bucket up the tube, like a long straw, at some point you can no longer raise the water level within the tubing. Measure the height of the water level within the tubing above the water level in the bucket. Try it also by inhaling, to draw up the water, instead of sucking.

Record your result and repeat the experiment for tubes of different diameter. Once you have collected the data you can determine the approximate vacuum pressure your lungs can achieve by themselves, and compare that to the best overall partial vacuum you are able to produce otherwise. *[Sal]*

3) Fermi, fer you

Enrico Fermi, a famous physicist of the 20th century, was well-known for asking peculiar questions of his students, intended to develop their practical ability to figure things out from reasonable assumptions and common knowledge (or good guesses!). In one of these 'Fermi Questions' he's reported to have asked "How many piano tuners are there in Chicago?" The point was to figure it out on the spot, not to contact the Tuners' Guild, and the reasoning might have started with a guess of what fraction of households even owned a piano — based, for instance, on thinking about your own friends' households. Then for a typical piano-owner, how often might one hire a tuner — maybe every year or two on average? In the end, one could figure out how many worker-hours of piano tuning per year there would be in a city the size of Chicago, and thereby figure out how many tuners could be supported by that amount of work.

Try these yourselves! You'll have to make a number of assumptions or approximations — please describe each on a separate line, with the numerical estimate or guess you make. Any final answer within a factor of three of the 'real' answer is considered an excellent success, for others a factor of ten is good. Your *thinking* is the main thing of interest to us — please don't go and measure anything, or look anything up.

a) How many piano tuners do you figure there are in Toronto?

b) I saw lots of meteors streak across the sky this summer — they moved through an arc of about 45 degrees of the sky in a little less than a second. How fast do meteors go?

c) How many kilograms of toothbrushes do the people of Canada throw away each year?

d) If icebergs never broke off from the ice-caps at the poles of the earth, roughly how long would it take to tie up all the water on earth as ice at the poles?

e) How many atoms scuff off your sneakers onto the sidewalk with each step you take?

[Robin]

4) Number four with a bullet

A 2 g spherical bullet 9 mm in diameter is fired from a gun at 250 m s^{-1} into one end of a thermally insulated cylinder. The cylinder, 15 m long and with a diameter of 1 m, is pressurized to 20 atm with Argon gas at room temperature. While passing through the cylinder, the bullet experiences a drag force which slows the bullet:

$$F_{drag} = -\frac{1}{2}\varepsilon\rho A v^2$$

where ε = coefficient of drag (a constant)
ρ = density of gas
A = cross-sectional area (area of an object's shadow)
v = speed

Ignore gravity, and assume ideal gas behaviour.

Eventually, the bullet hits the opposite end of the cylinder and stops.

a) How long does it take for the bullet to reach the opposite end of the cylinder?

b) Calculate the bullet's velocity just before hitting the cylinder wall.

c) Calculate the change in temperature of the Ar gas in the cylinder due to the bullet's motion before impact.

[HINT: If you can integrate, you can do this; if you get stuck, check the POPTOR webpage for ways to solve the quite simple *differential equation* you will get]. *[Brian]*

5) Bubbling ideas

Suppose we have a perfectly round soap bubble of initial radius R_o, with internal air pressure p, and external air pressure p_o.

a) What is the change of pressure inside the bubble if the bubble size is increased by a small amount?

Now put a charge Q on the bubble, spread evenly over the surface.

b) What is the new radius of the bubble after charging it up?

[HINT: perhaps you know or can find the field *outside* a spherical charge distribution, and figure out the field *inside* too. But what about the field right on the bubble wall, *neither* inside nor outside? The right answer is a kind of averaging... *[Peter]*

6) Magnus matters

What does it take to pitch a curveball in baseball? Besides some talent, it takes just a bit of physics — the *Magnus* effect.

The drag force on a ball depends on how quickly it is moving through the air. When a ball is moving through the air and also spinning, the airspeed on one side of the ball is greater than on the other. So it isn't strange that the force on one side of a spinning ball can be greater than on the other, and the ball can be pushed sideways — curve in its path.

Here's a simple experiment to find out about this. You need:

a cardboard tube of the type that is found at the centre of a roll of paper towels
a skinny elastic band, at least 5 cm long
a sticky note, like Post-It™ brand

We want to drop the tube through the air while it is spinning. To do this, cut the skinny elastic band so that it's now just an elastic string. Attach one end of the elastic to the sticky-note, using tape (duct tape works well for me). Then stick the sticky note onto the cardboard tube right in the middle (as a kind of anchor) and wind the elastic around the tube. Now hold the tube horizontally while holding the free end of the elastic. Let go of the tube while keeping hold of the elastic — before it really falls, the elastic will pull on the tube and spin it up, and the sticky-note will peel off at the last.. It works best if you can release it over a balcony or from a ladder.

a) What happens to the tube as it falls? Does it make a difference which *way* the tube is spinning as you drop it? How does this compare to the way the tube falls if it isn't spinning at all? How do *you* explain the effect? How do you imagine the spinning motion changes the forces on the tube?

b) Measure how far the tube falls, and how much it moves sideways. You may need to make several trials, measuring each time, and average your answers together to get a reliable result. If you can figure out the error in your measurement, that's worth extra points. Can you tell what *path* or trajectory the tube takes as it falls — curved or straight? You might want to use a video camera and then look at the tape frame-by-frame to analyse things.

c) Use the results from (b) to figure out what the angle of descent is for the tube, relative to the vertical. You should probably find that the falling tube pretty quickly reaches *terminal velocity*, when the air drag-forces exactly match the force of gravity (for a parachutist in free-fall this is roughly 200 km per hour!). At what speed does the cylinder fall? Can you use this to figure out roughly how quickly the tube moves sideways?

d) *Theory* — this just takes some algebra, though it looks a little hairy. Bonus points! Use the F_{drag} formula from question 4; for anything shaped like a *cylinder*, the coefficient of drag is $\varepsilon = 1.0$. Can you use this to predict the terminal velocity of the falling spinning cylinder (you may also have to weigh your tube)? How does this compare to what you measured? You can likewise look at the sideways-motion terminal velocity. What must be the sideways force, to give the sideways terminal velocity you found above?

e) BIG BONUS: For a given cylinder and spin-rate, can you roughly predict the angle, relative to the vertical, at which the spinning tube should fall? *[Robin]*

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Drag force:

$$F_{drag} = \varepsilon \rho A v^2$$

where ε = coefficient of drag (a constant)
ρ = density of fluid
A = cross-sectional area (area of an object's shadow)
v = speed

$\varepsilon_{sphere} = 0.5$

$\varepsilon_{cylinder} = 1.0$

C_v (Ar) = 12.5 J mole^{-1} K^{-1} (heat capacity at constant volume)

M_m (Ar) = 39.948 g mole^{-1} (density of argon, per mole; *molar density*)

ρ_{air} = 1.2928 g L^{-1}