PRINCETON UNIVERSITY PHYSICS COMPETITION

Onsite Test 2014 Directions

The test consists of **three** questions which you will be given **2** hours to complete. Calculators are allowed. **No collaboration** is allowed and partial credit will be given for incomplete solutions.

Some useful test-taking hints:

1. You may not be able to complete every problem. Keep moving; do what you know first.
2. Make your answer clear by circling it.
3. Use symbols rather than numbers wherever possible and check units.
4. Whenever possible, check whether an answer or intermediate result makes sense before moving on.
5. If you get stuck on an early part of a problem, check the later parts – some may be independent and doable.
6. If you get stuck on an early part of a problem, and a later part depends on it, clearly define a symbol for the unknown answer and use it in later parts. However, keep in mind that we often give multiple parts to guide you through a problem.

To get full credit you need to show your work! Partial credit will also be awarded at the judges' discretion. The total number of points one can receive on the Onsite Test is 100. Each question will be weighed equally and is worth 30 points, but it does *not* necessarily mean that the problems are of comparable level of difficulty. Everyone starts with 10 free points.

Good luck!

Sponsors

We are very thankful for support from our University and corporate sponsors!

Jane Street

USG Undergraduate Student Government

PRINCETON UNIVERSITY PHYSICS COMPETITION

Onsite Test 2014

Question 1. **Disk in a gas.**

Imagine a disk of radius r moving with constant velocity v (perpendicular to the plane of the disk) in a certain contained volume of gas of density n that is in thermal equilibrium at temperature T. What is the drag force on the disk? *The answer does not have to be rigorous.* Assume that:

a. the gas molecules collide with the disk elastically,

b. the speed of the disk is slow compared with the average molecular speed, and

c. the disk is large compared to a molecule but small compared to the molecules' mean free path.

Hint: Finding the leading term in the force to within a numerical factor is sufficient.

Question 2. **Minimum energies.**

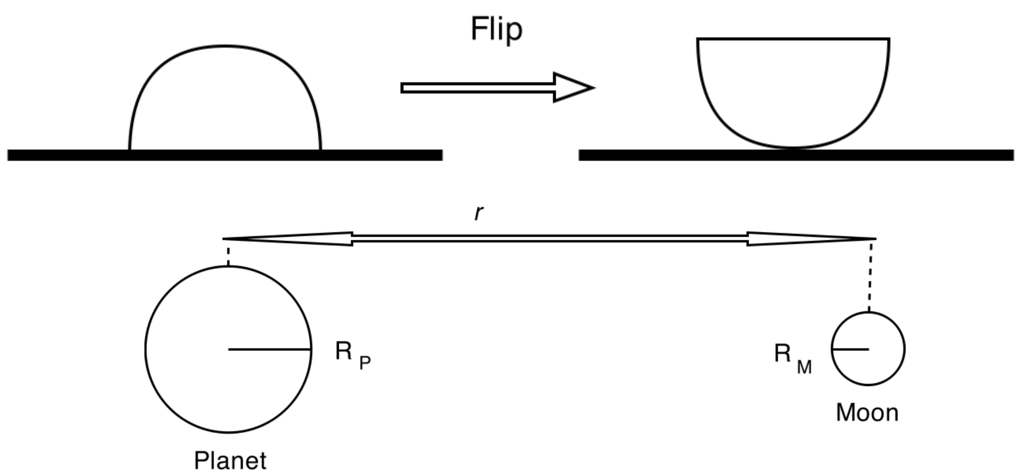

Figure 1: Wok on a table (*above*) and a planetary system (*below*) - see question 2

a) A wok, the famous Asian round-bottomed cooking vessel, can be modeled as a uniform hollow semi-sphere. Initially, you have a wok on your table with the open side down. What is the minimum energy needed to flip the wok such that in the end it has the open side up? *Assume that the wok is made of a metal sheet with surface density σ and that the gravitational acceleration is g.*

b) If we colonize other planets we will want to move easily between planets and their moons. Assume that you have a planet of mass M_P and at a distance r there is a moon of mass M_M, and you want to send a package of mass δ, from the planet to the moon. Assume that both the planet and the moon have their mass perfectly spherically distributed and that the radius of the planet is R_P and that of the moon is R_M. What is the minimum energy required so that you can transport the package between the planet and the moon? *Ignore* *any form of friction, any gravitational effects caused by any other body around the planet, and any corrections due to general relativity.*

Question 3. **Hitting walls.**

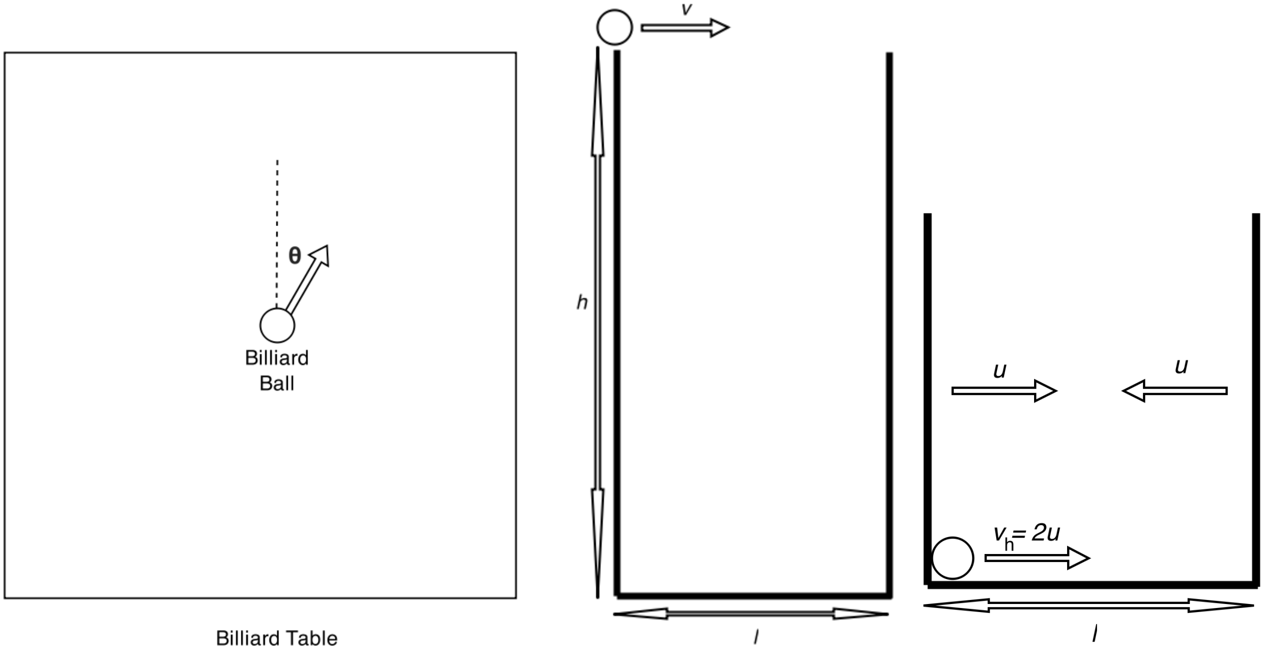

Figure 2: Billiard table (*left*), ball falling in well (*center*) and well collapsing (*right*) - see question 3

a) Assume that you have a single ball at the center of a square pool (billiard) table of side length l. You hit the ball under an angle θ as presented in *Figure 2* after which the ball has velocity v. Assuming that all collisions are perfectly elastic and that the ball hits the top wall first, how many times does the ball hit the walls of the pool table after some time t?

Ignore the corner cases in which the ball is hit precisely in the directions of one of the corners and ignore any form of friction in the system.

b) Consider launching a ball horizontally with speed v in a well of depth h which has two parallel walls that are separated by a distance l. Assuming all the collisions with the walls are perfectly elastic, at what distance from the wall on the left will the ball hit the ground?

c) At the bottom of the well the ball is still moving with some speed $v_h = 2u$ towards the right wall, starting precisely from the bottom of the left wall. Immediately after the ball starts moving, an earthquake begins and the well starts collapsing as the walls start moving towards each other with velocity u. Assume that the coefficient of restitution at each collision between the ball and the walls is $r = 1/3$. [1] What is the total distance that the ball covers until the two walls of the well hit each other? *Assume that during the collapse the walls always stay parallel to each other.*

[1] Remember, the coefficient of restitution is simply, $r = \dfrac{\text{Relative velocity after collision}}{\text{Relative velocity before collision}}$