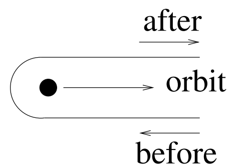
PHYS-3301 Winter Homework 5 Due 8 Feb 2017

This homework is due in the dropbox outside 2L26 by 10:59PM on the due date. You may alternately email a PDF (typed or black-and-white scanned) or give a hardcopy to Dr. Frey.

1. **Gravity Assist**

   One strategy to help space probes like *New Horizons*, which took many pictures of Pluto, reach the outer solar system is to "slingshot" around another planet. In the rest frame of the solar system as a whole, the planet moves in its orbit, while the probe starts out moving toward the planet opposite the orbital velocity. Then the probe whips around the planet and moves away in the same direction as the orbital velocity (see the figure).

   Suppose the planet is Jupiter, which has orbital speed about 13 km/s, and that our probe is initially moving at 3 km/s with respect to the sun before it encounters Jupiter. What is the probe's speed after the slingshot? Treat the slingshot as an elastic collision and take the limit that Jupiter's mass is infinite.

2. **Inelastic Processes**

   (a) *Barton 2.10 rephrased* A cannonball is launched in an arc with velocity $\vec{u}$. At the top of its trajectory, a chemical charge in it explodes into two parts of masses m_1 and m_2 that separate in the horizontal direction only. The explosion releases energy E, which essentially all goes into the kinetic energy of the cannonball pieces. Show that they are separated by a distance $(u_y/g)\sqrt{2E(m_1+m_2)/m_1m_2}$ when they land, where u_y is the initial vertical component of the velocity.

   (b) A hydrogen atom of speed u collides with a hydrogen atom at rest. The atoms are both initially in their ground states. What is the minimum value of u in m/s such that one atom enters its first excited state? *Helpful Information:* It takes about 10 eV of energy to raise a hydrogen atom from its ground state to its first excited state, the mass of a hydrogen atom is $m \sim 1$ GeV/$c^2 = 10^9$ eV/c^2, and $c = 3 \times 10^8$ m/s. Give your final answer to 1 significant digit.

3. **Swimming Up-River** *based on Hogg 1-4*

   You are on the west bank of a south-flowing river. The river flows at speed v past the ground, and you are able to swim at speed u in still water with $u > v$. Suppose you want to swim and land due east of your current location on the opposite bank of the river.

   (a) At what angle to the west-east axis must you aim yourself (and is it to the north or south)? Note: even though you are aiming differently, you end up swimming due east with respect to the ground.

   (b) What is your speed relative to the ground if you swim due east as described above?

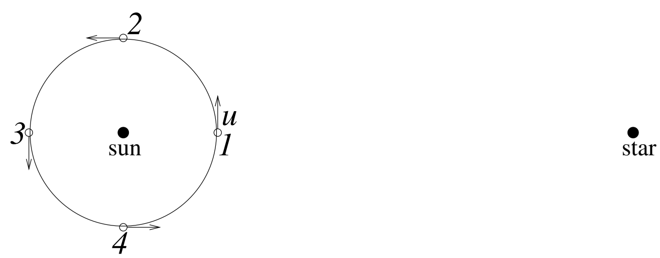
   (c) Explain briefly how this calculation relates to (part of) the Michelson-Morley experiment.

4. **Stellar Aberration**

In this problem we will explore more the aberration of starlight that was measured as far back as 1725. In this problem, all speeds of objects are small compared to the speed of light, so you are free to use Newtonian/Galilean relativity. You may want to recall that the speed of light is approximately $c = 3 \times 10^8$ m/s.

(a) First, to get a feel for how this works, consider the following situation. You're driving in a car, and it's raining. Relative to the fixed earth, the rain falls straight down with speed w, and you drive at speed u. At what angle from the vertical do you see the rain falling?

(b) Now, suppose there is a star straight overhead compared to your telescope. However, the earth is at position 1 in its orbit around the sun (see the figure below), where the orbital speed of the earth is approximately $u = 30,000$ m/s. At what angle from the vertical must I, standing on the earth, aim my telescope so that light from the star falls down the telescope tube? You may ignore the rotational speed of the earth's surface, which is much smaller than the earth's orbital speed. *Hint:* Recall that $\tan\theta \approx \sin\theta \approx \theta$ for small angles θ.



Note that the figure is not to scale; the star is far enough away that it is effectively directly overhead (at the appropriate time of day) no matter where the earth is in its orbit. Give the angle in arc-seconds, where 3600 arcsec equal 1 degree.

(c) At which point(s) as labeled in the figure above is this angle of aberration maximized? At which points is it minimized?