Assignment X, PHYS 111 (General Physics I)
Fall 2021
Due 11/11/21

Just as a reminder – in each homework assignment, I will list suggested homework problems out of the book. These are worth practicing – some may even appear on exams verbatim – but since they are in the text, finding answers on-line should be straightforward and these textbook problems will not be graded. I suggest you do them – many of them will be easier than the graded homework and they would be a good thing to tackle in your SI sessions to get comfortable with the content.

After the suggested book problems, I will give a list of problems that I myself wrote. *SOME* of these problems will be graded, but you won't know which ahead of time. The ones that I grade will be the same for everyone in the class.

I will supply you with an answer key to all of the problems that I wrote – even the ones that I did not grade.

As always, please legibly write (or type) your answers on separate paper. Incorrect answers with no work will earn nearly no credit, and consistent correct answers with no work are suspicious – many of these problems your professor can't do in his head, so it is unusual if you can. Please show all relevant work.

To help with this homework, you should read the associated sections of your text and watch the videos associated with the lectures on the course webpage: http://larsenml.people.cofc.edu/phys111_fall21.html.

(Ungraded) suggested textbook practice problems

(All problems are odd problems (that have answers in the back of the book) out of Halliday, Resnick, and Walker, 10th Ed.) Some problems from previous chapters that are related to recent lecture content have been included.

(Same as from previous HW with just a couple additions):
Chapter 11:
Problems: 3, 5, 7, 11, 19, 23, 27, 33, 37, 39, 45, 49, 51, 55, 57, 79, 83, 85

Graded Homework Problems

1. Under certain circumstances, a star can collapse into an extremely dense object called a neutron star. (1 tablespoon full of a neutron star has approximately the same mass as the whole Earth). Let's talk about a star that has an initial radius 9×10^8 m that collapsed down into a neutron star that has a radius of about 2×10^4 m. You may assume that the mass of each star before and after collapse is uniformly distributed throughout its volume (though clearly with a different density before and after it collapses).

   a) If no mass is lost in the transformation process, what is the rotational period of the neutron star if the original star had a rotational period of 2 weeks? (Leave your answer in seconds).

   b) Find the ratio $\frac{[v_{\text{rim}}]_{\text{neutron star}}}{[v_{\text{rim}}]_{\text{original star}}}$, where v_{rim} corresponds to the velocity of a piece of the star at the surface and on the equator of the rotating star.

2. I once visited a data center that used a giant flywheel to "store" kinetic energy that would enable the entire facility to keep running for a few seconds after a power-outage. The idea behind this is that you use a motor to get a system with a large amount of rotational inertia rotating while the power is still on and keep the thing rotating at all times while the power is on. If the power goes off, the flywheel will still keep turning for a little while and the motion of that flywheel can power your building's electricity through its motion (much like a turbine or water wheel). The details are unimportant for this problem, other than the fact that you can take the rotational energy of the flywheel and convert it back into electrical energy to power the thing you care about for a little while.

   a) If the flywheel is a horizontally-mounted uniform circular cylinder of density ρ, radius R, and height H, and rotates at a frequency of f rotations per second, how much kinetic energy is stored in the motion of the flywheel? (Leave your answer in terms of variables in the problem statement only).

   b) Let's say that the building had to power 300 computers, each requiring 500 Watts to keep running. You want your flywheel to power everything for 10 seconds – enough time for backup generators to kick on and start running to take over. The flywheel is constructed from a solid steel disk. (The density of steel is 7600 kg/m^3). If the flywheel is 0.1 meters thick, and is rotated at a constant velocity of 3 rotations per second about its center, what would its radius have to be in order to meet the energy requirements to keep the computers running for 10 seconds? Assume all energy stored in the flywheel's motion can be completely converted back to electrical energy with perfect efficiency. You do not have to worry about the kinematics/deceleration of the flywheel – I'm just asking for the radius required so that the total amount of energy matches the energy needed to run the computers for 10 seconds.

      (In case you are curious, the data-center's old solution to this problem was to use a bank of several hundred car batteries to do this task for them. That solution ended up being impractical).

   c) What is the magnitude of the angular momentum of the disk in part (b) when it is rotating at 3 rotations per second?

3. A wheel of radius R and mass M can distribute that mass M in a variety of ways – it can essentially be a hoop (if only very small massed spokes are used to connect the outer edge of the wheel to the axle), it can be very much like a cylinder (or its two dimensional version, a disk) (if there is a continuous mass distribution between the axle and the edge of the wheel), and – although unusual – it can be spherical (with the axle going through the wheel's center). Essentially anything with a circular shadow when illuminated from above can work. That being said, I'm going to claim that the moment of inertia of ANY wheel of mass M and radius R must be less than or equal to MR^2. Give a compelling and logically consistent argument either for or against this claim.

4. A negligibly thin rod of length $2L$ runs along the x-axis from the point $-L\hat{\imath}$ to the point $L\hat{\imath}$. The ends of this rod mark the midpoints of two solid spheres, each with radius $R < L$ (so that there's a sphere of radius R centered at each of the two end points $-L\hat{\imath}$ and $L\hat{\imath}$). (This system looks like an old-school "barbell"). Let the rod have mass m and each sphere have mass M. By construction, the center of mass is at the origin no matter what m and M are.

   a) Find the moment of inertia of the whole system through the axis that goes through the origin and points in the $\hat{\jmath}$ direction. (The moment of inertia with respect to this axis is often abbreviated as I_y to indicate that this is the moment of inertia with respect to the y-axis).
   (Hint/reminder: if you have a compound object, I for the system is equal to the sum of I for the parts of the system. Also note that you will need to use the parallel axis theorem, since we are *not* rotating the spheres about their centers).

   b) Find the moment of inertia of the whole system through an axis going through the origin and pointing in the $\hat{\imath}$ direction (a.k.a. I_x).

   c) Introductory texts give the following simple approximation of the nuclear radius: $R \approx (1.2 \times 10^{-15}\text{ m})A^{1/3}$ where A is the number of protons and neutrons in the atom. The bond-length of an N_2 molecule is approximately 145×10^{-12} m. Assuming that the bond itself has negligible mass, calculate the ratio between I_y/I_x for an N_2 molecule using the basic "barbell" picture described above. Your final answer should be a number – no variables should appear in your final answer to this part of this problem.

5. Two astronauts, each with mass M, are connected by a rope of length d having negligible mass. They are isolated in space, orbiting their center of mass with each moving at speed v. Calculate:

   a) The magnitude of the angular momentum of the system (in terms of M, v, and d). (Assume the astronauts are point particles).

   b) The rotational energy of the system (in terms of M, v, and d).

   By pulling the rope, the astronauts shorten the distance between them to $d/2$.

   c) What is the new angular momentum of the system? (again, in terms of M, v, and d).

   d) What are their new speeds?

   e) What is the new rotational kinetic energy of the system?

   f) How much work is done by the astronauts in shortening the rope?

6. A wedge of height h and wedge-angle θ has a number of different items move down it. Your answers to all parts of this problem should be in terms of m, R, h, θ, and fundamental constants *only*!

a) If a solid sphere of radius R and mass m starts from rest at the top of the wedge and rolls down the wedge without slipping, how long does it take the sphere to reach the bottom of the wedge?

b) If a uniform disk of radius R and mass m starts from rest at the top of the wedge and rolls down the wedge without slipping, how long does it take the disk to reach the bottom of the wedge?

c) If a hoop of radius R and mass m starts from rest at the top of the wedge and rolls down the wedge without slipping, how long does it take the hoop to reach the bottom of the wedge?

d) If a mass (irrelevant shape) of radius R and mass m starts from rest at the top of the wedge and *slides frictionlessly* down the wedge, how long does it take the mass to reach the bottom of the wedge?