Massachusetts Institute of Technology - Physics Department

Physics - 8.01 **Assignment #8** November 8, 1999.

It is strongly recommended *that you read about a subject* **before** *it is covered in lectures.*

Lecture Date	Material Covered	Reading
#25 Wed 11/10	Static Equilibrium - Stability - Rope Walker	Page 354 – 364
#26 Fri 11/12	Elasticity - Young's Modulus	Page 365 – 369
#27 Mon 11/15	Fluid Mechanics - Pascal's Principle - Hydrostatics Atmospheric Pressure Over Pressure in Lungs and Tires	Page 466 – 478
#28 Wed 11/17	Hydrostatics - Archimedes' Principle - Fluid Dynamics What makes your Boat Float? - Bernoulli's Equation	Page 478 – 483

Due Wednesday, Nov 17, before 4 PM in 4-339B.

This is not an easy assignment. You have 9 days; START EARLY!

8.1 *Conservation Laws*
Imagine a spherical, non-rotating planet of mass M and radius R that has no atmosphere. A satellite is fired from the surface of the planet with speed v_0 and at 20° to the local vertical. In its subsequent orbit the satellite reaches a maximum distance of $5R$ from the center of the planet. Calculate v_0.

8.2 *Much Ado About a Ham Sandwich*
You can find this problem in the Lecture Supplement (on the Home Page) of Nov. 3. This supplement gives you all the necessary background as discussed in lectures.

8.3 *Going to the Sun*
A spacecraft of mass m is first brought into an orbit around the earth. The earth (together with the spacecraft) orbits the sun in a near circular orbit with radius R (R is the mean distance between the earth and the sun; it is about 150 million km).

a) What is the speed of the earth in its orbit around the sun?

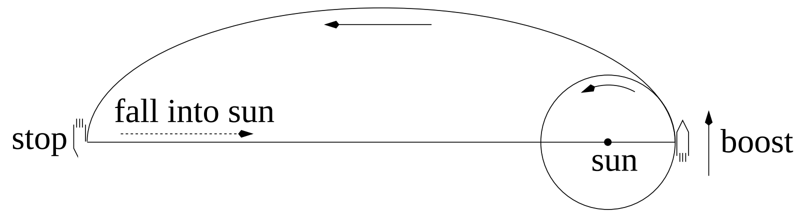
We want the spacecraft to fall into the sun. One way to do this is to fire the rocket in a direction *opposite to the earth's orbital motion* to reduce the spacecraft's speed to zero (relative to the sun).

b) What is the total impulse that would have to be given by the rocket to the spacecraft to accomplish this? You may ignore the effect of the earth's gravitation as well as the orbital speed of the spacecraft around the earth as the latter is much smaller (how much smaller?) than the speed of the earth around the sun. Thus, you may assume that the spacecraft, before the rocket is fired, has the same speed in its orbit around the sun as the earth.

We will now show that there is a more economical way of doing this (i.e., a much smaller rocket can do the job). By means of a brief rocket burn the spacecraft is first put into an elliptical orbit around the sun; the boost is provided tangentially to the earth's circular orbit around the sun (see figure). The aphelion of the new orbit is at a distance r from the sun. At aphelion the spacecraft is given a backward impulse to reduce its speed to zero (relative to the sun) so that it will subsequently fall into the sun.

c) Calculate the impulse required at the first rocket burn (the boost).

d) What is the speed of the spacecraft at aphelion?



e) Calculate the impulse required at the second rocket burn (at aphelion).

f) Compare the impulse under b) with the sum of the impulses under c) and e), and convince yourself that the latter procedure is more economical.

g) Make a specific quantitative comparison for $r = 20R$.

8.4 *Black hole in X-Ray Binary*
An X-ray binary consists of 2 stars with masses m_1 (the accreting compact object) and m_2 (the donor). The orbits are circular with radii r_1 and r_2 centered on the center of mass.

a) *Derive* the orbital period of the binary following the guidelines given in lectures.

b) In the case of Cyg X-1 (as discussed in lectures), the orbital period is 5.6 days. The donor star is a "supergiant" with a mass 30 times that of the sun. Doppler shift measurements indicate that the donor star has an orbital speed v_2 of about 148 km/sec. Calculate r_2.

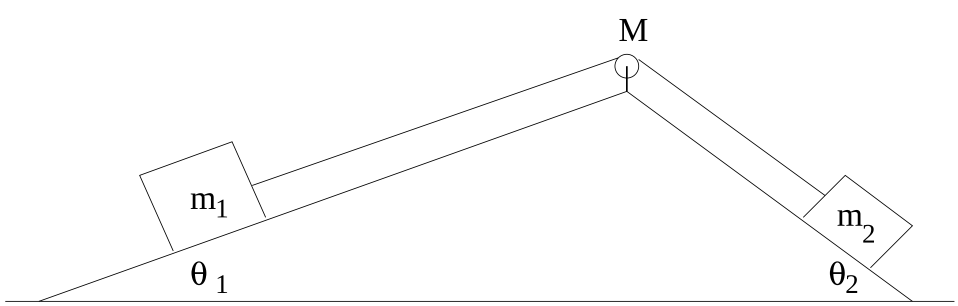
c) Calculate r_1. Your calculations will be greatly simplified if instead of r_1 you set up your equations in terms of r_1/r_2. Once you have solved for r_1/r_2, you have found r_1 as you already know r_2 (see part b). You will find a third order equation in r_1/r_2. Only one solution is real; the other two are imaginary. There are various ways to find an approximation for r_1/r_2. You can find the solution by trial and error using your calculator, or you can plot the function.

d) Now calculate the mass m_1 of the accreting compact object.
As discussed in lectures, since this turns out to be substantially larger than 3 times the mass of the sun, it is strongly believed to be a black hole.

8.5 *Rolling and Slipping Hoop* – page 352, problem 45

8.6 *Physical Pendulum* – page 409, problem 34

8.7 *Two Blocks, Two Slopes and a Pulley*
Two blocks m_1 and m_2 are connected by a light string (with negligible mass) passing over a pulley with mass M and radius R as shown. The pulley is a solid uniform disk, and the friction between it and the rope is such that when the blocks move the rope turns the pulley without slipping. The kinetic friction coefficient between the blocks and the slope is μ. Find the acceleration of the blocks, the angular acceleration of the pulley, and the tension in each part of the rope. Assume that m_2 is much larger than m_1 (the blocks go from left to right), and that the bearings of the pulley rotate without friciton.



8.8 *Doppler Effect I* – page 462, problem 29

8.9 *Landing Aircraft*

An aircraft lands at a speed v. Before it touches down, its wheels are not rotating. Describe in words what happens when the wheels touch the ground. Assuming that each wheel has radius R and moment of inertia I and supports a weight Mg, and that that the pilot does not apply reverse thrust until the aircraft is no longer skidding, how fast is the plane moving when it stops skidding?

8.10 *Toy Gyroscope* – page 353, problem 50

8.11 *Flywheel to Stabilize Ship* – page 353, problem 51

8.12 *Spin Stabilization*

Angular momentum can make a freely moving object remarkably stable. To analyze the effect of spin, consider a cylinder (mass m, length l, and radius r) moving freely in space. Suppose that a small perturbing constant force F acts on the cylinder for time Δt. F is perpendicular to the cylindrical axis of symmetry, and the point of application is a distance d from the center of mass. We want you to first consider the case where the cylinder has zero spin about its axis of symmetry.

a) Calculate the precession angular velocity ω which results from this impulse.

Now consider the same situation except that the cylinder is rapidly spinning about its axis with angular momentum L.

b) Calculate the angle through which the cylinder precesses in time Δt. Notice the cylinder now slightly changes its orientation while the force is applied and then stops precessing. The faster the spin, the smaller is the angle, and thus the smaller is the effect of the perturbing force.