# Physics 200 Problem Set 5

## Problem 1

a) A black jelly-bean weighing 1g sits in the middle of a round frictionless table, 1m from the edge. At time $t = 0$, a 1W laser is turned on to shine directly at the jelly bean. At what time will the jelly bean fall off the table, assuming that it absorbs all the light incident on it? (Hint: to do this problem exactly, we would have to take into account the fact that the mass of the jelly bean is changing slightly. However, this is not significant here, so ignore the change in mass for this part of the question. You will see whether this is justified in part b.)

b) Roughly how much heavier will the jelly bean be when it falls off the table than when it started?

c) If we started with a white jelly bean instead, would the time in part a be larger or smaller and why?

## Problem 2

One day at Heather's Particle Creation Station (longtime rival of Dave's New Particle World), Heather collides some particles and produces a new short-lived unstable particle at rest, which then decays to a tau particle (mass $1777MeV/c^2$) and a photon (a massless particle of light). If the tau particle is observed to have energy 4000MeV, what is the mass of the unstable particle that Heather created?

*By the general relation $E^2 = p^2c^2 + m^2c^4$, a particle with zero mass has energy and momentum related by $E = |\vec{p}|c$. The formula $E = \gamma mc^2$, implies that the only way for a particle with zero mass to have finite energy is for $\gamma$ to be infinite, so the particle must travel at the speed of light. For such particles, the velocity doesn't determine the energy and momentum (the formulae $E = \gamma mc^2$ and $p = \gamma mv$ aren't really useful for massless particles). We just have to independently say what the momentum of such a particle is, and then the energy is determined from the momentum by $E = |\vec{p}|c$.*

## Problem 3

In this problem, we will estimate the lifetime of a "classical" Hydrogen atom. As we'll discuss in class, the classical model of an electron orbiting a proton is flawed, because accelerating charges radiate energy, so an orbiting electron would produce radiation, lose energy, and spiral into the nucleus.

a) For an electron in a circular orbit around a proton at a radius $r$, what is the acceleration as a function of $r$?

b) Using the result from part a), determine the velocity of the electron as a function of $r$ (remember circular motion?).

c) Determine the total energy (kinetic plus potential) of the electron as a function of $r$.

d) Classical electromagnetism tells us that the accelerating charges radiate energy at a rate of

$$P = \frac{e^2 a^2}{6\pi\epsilon_0 c^3}$$

This tells us how much energy the electron will lose per unit time. Using this, and your result for part c), derive an equation for $dr/dt$ in terms of $r$ (hint: you can use the chain rule to relate $dr/dt$ to $dE/dt$ and $dE/dr$). Assuming the initial of the orbit is $10^{-10}m$, divide the initial radius by $dr/dt$ to estimate the lifetime of the atom, or solve the equation relating $dr/dt$ to $r$ to get a more precise answer.

## Problem 4

A perfectly absorbing ball of radius $10cm$ sits $10m$ away from a $100W$ lightbulb that emits light uniformly in all directions. By how much does the mass of the ball increase in 1 year (assume that all the power expended by the lightbulb goes into electromagnetic radiation and that the ball does not move)?