**Recitation Problems for Week 6, Thursday**

4.C7. The force that confines quarks inside protons is known to be about sixteen tons. It is known that $9800\,N$ corresponds to about one metric ton. It is also known that this force is constant over distance scales typical of nuclear sizes, ($10^{-15}\,m$). (a) How much energy is required to pull a quark a distance of $2 \times 10^{-15}\,m$ from a proton? (b) How does this energy compare to the rest-mass of the proton?

4.S41. A small asteroid of mass $10^{18}\,kg$ starts from very far out in the solar system. Due to an encounter with a passing star, the object is perturbed and it starts to fall into the solar system. It travels in, swings around the Sun, and then on its way back out it collides with the planet Jupiter. (a) What is the speed of the rock when it crosses the orbit of Jupiter on its way in? (b) What is the speed of the rock just before it collides with Jupiter?

4.S54. A exciting outdoor activity is bungee jumping. Here, you attach an elastic rope to each of your ankles, and then jump off some elevated structure such as a bridge or a tower. If the ropes have been chosen correctly, you will come to a smooth stop just before you hit the ground. However, if you fail to choose the correct ropes, the result can be rather disasterous! If we model the ropes as two springs in parallel, then we can make some reasonable estimates for how stiff our ropes need to be. (a) Consider that you start a distance $h$ above the surface of the Earth, the unstretched length of the rope is $L$, and the rope has an effective spring constant $k$. Assuming that you have a mass $m$ and start from rest, how long can the rope be, $L$, to make sure that you don't hit the ground? (b) What is the stretch of the rope when your speed is a maximum? (c) What is the maximum tension in the rope as you fall? (d) Take $m = 50\,kg$ and $h = 30\,m$ and $L = 15\,m$. What is the minimum value if $k$ for the rope, and what is the maximum tension in the rope?

4.S60. A proton and a neutron at rest combine to form a deuteron, the nucleus of heavy hydrogen. During this process, a gamma ray is emitted whose energy is $E_{gamma} = 2.2\,MeV$. (a) Assuming we can ignore the recoil of the resulting deuteron, what is the mass of the deuteron to five significant figures? (b) In fact, we must have momentum conservation with the gamma-ray and the resulting deuteron having equal and opposite momentum. What is the momentum of the deuteron? (c) What is the final kinetic energy of the deuteron? (d) Was it reasonable to ignore this energy?

4.S61. An ideal pendulum is approximated as a stiff, massless rod of length $L$. The upper end is free to pivot about a point, and a point-mass $m$ is attached to the lower end. The pendulum is then free to oscillate about the pivot. We characterize the oscillation with the angle $\theta$ which measures the angle at the pivot of the rod. (a) What is the gravitational potential energy of the pendulum as a function of $\theta$. (b) Sketch the

potential from $\theta = -60^\circ$ to $\theta = 60^\circ$. (c) What initial speed will the pendulum bob need to be able to rise above the height of the pivot? (d) In polar coordinates, $(r, \theta)$, the force expression is given as

$$\begin{aligned} F_r &= -\frac{dU}{dr} \\ F_\theta &= -\frac{1}{r}\frac{dU}{d\theta}\,. \end{aligned}$$

For the bob held fixed at some angle $\theta$, what is the force acting on it?