NYU Physics I—Problem Set 12

Due Thursday 2016 December 1 at the beginning of lecture.

Problem 1: What is the most expensive ingredient of a typical, traditional Thanksgiving dinner *by weight* (that is, in dollars per ounce or per pound). Start with the turkey and show your work (that is, compare some ingredients). What is the relevance of all this to world history? Keep it traditional—traditional food with traditional ingredients. You might want to discuss with someone who cooked a Thanksgiving dinner (or did the shopping for it).

Problem 2: *(a)* Sketch orbits of fixed semi-major axis but increasing eccentricity, from a circular orbit, to one that is close to radial (eccentricity close to unity).

(b) What is the transfer time for a radial plunge orbit from the radius of the Moon's orbit down to the surface of the Earth? Use the period of the Moon's orbit, the relevant Kepler's law, and the properties of the unit-eccentricity and circular orbits.

(c) Look up the timeline of the Apollo 11 mission, especially the return to Earth. Do you see any issues there? What's your best explanation of what happened?

Problem 3: *(a)* How fast do you have to move with respect to the Earth's surface to escape Earth's gravity? That is, what is escape velocity from the Earth. Calculate it yourself in terms of the radius R of the Earth and the value of g at the surface. Then give it also in $\mathrm{m\,s^{-1}}$.

(b) A spaceship of mass m resting on the surface of the Earth is bound to the Earth but also to the Sun. If we make the naive (and close to correct) assumption that these energies just add, what is the total binding energy of the spaceship in the Solar System? This calculation can be confusing, because although you can assume the spaceship is stationary with respect to the Earth (so there is only gravitational potential energy with respect to the Earth), the spaceship is moving fast relative to the Sun (so there is both gravitational potential and kinetic energy with respect to the Sun). The best way to do the calculation is to just pick the Newtonian reference frame centered on the Sun, and compute the kinetic and potential energies in that frame. Now what is the escape velocity from the Solar System? Give your answer in $\mathrm{m\,s^{-1}}$.

(c) Look up the derivation of how a rocket accelerates. You should be able to find a rocket equation that relates the initial mass of the rocket+fuel, the final mass of the rocket after the fuel is spent, the speed at which the rocket ejects exhaust, and the final speed of the rocket. (Hint: The equation is exponential in a mass ratio.) If the rocket can eject exhaust at 10 times the speed of sound in air at STP (and that's optimistic!), what is the ratio of initial mass to final mass of a rocket that will leave the Solar System? What is the maximum fraction of the spaceship initial mass that can be used for payload—that is, for cabin, crew, and cargo?

(d) Now imagine the spaceship is going to another planet just like the Earth. What fraction of the spaceship can be used for non-fuel payload in this case? The point is that it takes just as much velocity change to slow down at the end of the journey as it took to take off at the beginning, and that the end-of-flight fuel is part of the cargo that the ship has to take with it at launch. You should get that the payload fraction is (something like) the square of what you got in the previous part.

Extra Problem (will not be graded for credit): What do you think the above problem means for interstellar travel?

Extra Problem (will not be graded for credit): Make a spreadsheet integration that integrates a test-particle (low-mass) orbit in the central force law, and show that you do indeed get an elliptical orbit. You want to use a time step that is < 0.001 of the period and go for > 1000 timesteps if you want the integration to look good! This integration is harder than other integrations you have done in this class, because you have to project the force onto the x and y directions correctly. That is, you have to keep track of both x and y positions, velocities, and accelerations. Do the problem in the two-dimensional plane of the orbit. If you want feedback or get stuck, bring your intermediate work to Prof Hogg for discussion.