HW1

- Reading assignment: Einstein chapters 1-6
- For the problems below, please show all work!
- Reading assignment: Road to Reality chapter 1 handout – This is optional. You will not be accountable for this reading which is intended to provide some food for thought.

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1. Newton's law of gravitation is given by the equation below, where F is the gravitational force, M and m are masses, and r is the length. Force has units of kg$\times\frac{m}{s^2}$. What are the units for the constant G?

$$F = G\frac{Mm}{r^2}$$

2. The speed of light is about $3 \times 10^8 m/s$. (a) Convert this to miles per hour. (b) If the sun is about 93×10^6 miles from Earth, provide an order of magnitude estimate for how long it takes the sun's light to reach Earth.

3. Quantum gravity is any theory which (correctly) describes the gravitational force using quantum mechanics and has been the Holy Grail of theoretical physics for the past few decades. For now we can think of gravity to be described by the equation in problem 1. While we won't discuss quantum mechanics, Plank's constant $\hbar$, which is given in units kg$\times m^2/s$, characterizes phenomena for which quantum mechanics is important. Without knowing anything about quantum mechanics or quantum gravity we can use dimensional analysis to define the so-called Plank length and Plank time. Using the constants $\hbar$, speed of light c, and the gravitational constant G (and nothing else!) try to find a combination (Hint: first compute the dimensions of $G\hbar/c^3$) which yields units of i) length ii) time. Using the internet, find numerical values for these constants and provide an order of magnitude estimate for the Plank length and time. Physical phenomena characterized by these scales, for example the big bang and black hole evaporation, require a quantum theory of gravity.

4. In chapter 2 of Einstein's book he discusses three ways of measuring the distance to a cloud above Trafalgar square in London, let us focus on the first two: a) build a coordinate system consisting of equally spaced markers and measure distance by counting the number of markers between the ground and the cloud and b) locate the cloud and directly measure the distance with, say, some measuring tape or long ruler. While these two approaches might seem similar, they are actually a bit different which can be seen if the cloud drifts to the right. Suppose the cloud was initially 1000 meters above ground and drifts 100 meters to the right. Repeat Einstein's first measurement experiment mentioned above. Describe (and draw) how you would build a "two dimensional" coordinate system by laying down rulers from the ground up and to the right. Find the clouds's distance from Trafalgar square by using the Pythagorean theorem.

5. OPTIONAL – HARDER Remember you are always free to choose your own coordinate system! A smarter choice of coordinate system for measuring the drifted cloud in problem 4 would be one which you lay down equally spaced markers directly connecting Trafalgar square and the cloud. Taking Trafalgar square to be the origin of the coordinate system, relate this smarter coordinate system to the one you constructed in problem 4 by a rotation about the origin. Write down how the coordinates (i.e. x and y values) of the two systems are related. Finally, use this relationship to show that observers using either coordinate systems will agree on their distance measurement. You have "discovered" a fundamental property of the Universe: observers (i.e. coordinate systems) related by rotation will agree on distances between two points. When we come to talk about special relativity we will see distance is NOT preserved when two observers are moving relative to one another.