1. The Magic of Ratios in using Kepler's 3rd Law.

Application of Kepler's Third Law is made **a lot easier** by using ratios; i.e., comparing the period and orbital radius of some unknown object to that of the Earth. Since the period of the Earth's orbit is 1 year \( (P = 1 \text{ year}) \) and the radius of the Earth's orbit is 1 Astronomical Unit \( (a = 1 \text{ AU}) \): \[ P^2 = \text{[constant]} \times a^3 \]

requires constant = 1 if periods \( (P) \) are in years and orbital radii \( (a) \) are in AUs. So, using the right units makes things easy:

\[ P^2 \text{ [years]} = a^3 \text{ [AUs]} \]

where the correct units to use are in the brackets

(a). Using Kepler's Third Law (quoted above) determine the orbital period of Pluto, whose orbital radius is 40 AU (on average; its orbit is quite elliptical).

SHOW YOUR CALCULATION HERE:

Pluto was discovered in 1930. Approximately what percentage of Pluto’s full orbit have we observed so far? __________

(b). Kepler's Third can be "tricky" in that the constant in \( P^2 = \text{constant} \times a^3 \) is **not the same constant** in all circumstances. It **does** have the same value for all objects orbiting the Sun, but has a different value for objects orbiting some other gravitational center (e.g., the constant for the Earth’s Moon (and anything else orbiting the Earth) is different from that used for Jupiter’s Moons…and anything else orbiting Jupiter).

With this in mind use Kepler's Third Law to determine the orbital radius (distance above the center of the Earth) for an artificial satellite in "stationary orbit". A stationary orbit is an orbit which rotates at the exact speed that the Earth rotates \( (P = 24 \text{ hours} = 1 \text{ day}) \) and so stays at a fixed location above a single point on the Earth's surface. **SHOW YOUR WORK!**

Use the ratio method by noting: \( a \text{ (Moon)} = 238,000 \text{ miles} \) and \( P \text{ (Moon)} = 27.3 \text{ day} \) orbital period relative to the stars.
(c). Each of Kepler’s Three Laws can be derived from Newton’s law of Gravity. Specifically, \( P^2 [\text{years}] = k a^3 [\text{AUs}] \) where Newton showed that \( k = 4\pi^2/GM \), where \( G \) is the Gravitational constant and \( M = \) mass of central object in Solar masses (mass of object being orbited in units of the Sun’s mass). That is, when the period is expressed in years, the orbit size expressed in AU, then the mass of the central object can be calculated in Solar masses: i.e., \( M [\text{Solar masses}] = a^3 [\text{AUs}] / P^2 [\text{years}] \) \{EQUATION #1\}

Wonderfully, this allows us to determine the mass of any massive object being orbited if we can observe the (period + size of orbit) or (velocity + size of orbit) or (velocity + period of orbit); i.e., any two of these three quantities AND as long as \( M(\text{orbiter}) < < M(\text{orbitee}) \).

Explore this capability as follows:

1. Visit the Galactic Center imaging project at the following website: http://www.astro.ucla.edu/~ghezgroup/gc/pictures/orbitsMovie.shtml

   This animation records the locations of all the luminous stars in the Center of our own Galaxy over the last few years. The lines and dashed lines trace out the orbits of these stars. The large star is at one focus of all these orbits. NO LIGHT comes from the location of the star despite being the gravitating center for these stars; i.e., it is a Black Hole.

2. Use Equation #1 to determine the mass of the Black Hole at the Center of the Milky Way. To do this, use the orbit of star SO-2 whose period is given in the caption. Estimate the size (approximate average radius) of the orbit of SO-2 using the scale shown on the images and using 1” (1 arcsecond) = 8.5 \times 10^3 \text{AU}. Only an approximate orbit size is required. {All large galaxies appear to have super-massive Black Holes like this one at their Centers!}

II. Position paper: What is the Nature of Time? Specifically, is Time an observed “fact” (i.e., a direct observable in the inductive method) or rather a theoretical construct or model in the deductive method? Explain your reasoning.

In this essay describe how Time fits into the framework of modern physical theory which includes:

Particle (the “players”)
Motion
&
Forces

Also include in your essay the concept of “cause and effect” and its role in using theory to predict the outcome of observations and experiments.

*** OF COURSE, I DO NOT EXPECT THAT YOU ARE AN EXPERT ON THIS SUBJECT. IN TRUTH, NO ONE IS.