Course and Section_____ Names _____

Date_____ _____

UNIVERSAL LAW OF GRAVITY

Introduction

Newton's universal law of gravitation states that the force of attraction between two objects with masses *M* and *m* separated by a distance *d* has magnitude

$$F = G\frac{M\,m}{d^2}$$

where *G* is universal gravitational constant = 6.67 x 10^{-11} Nm^2kg^{-2}.

Submit your answers using Blackboard.

1 – Preliminary Question

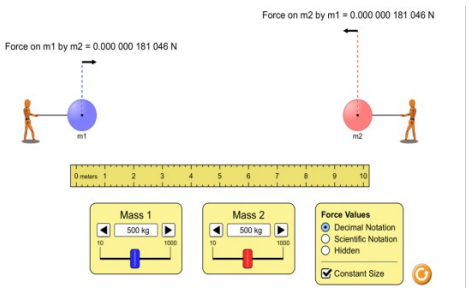
1. Find the force of attraction between you and your friend. Assume you both have same mass of 90 kg and that you are 1.0 m apart. (N)
2. What is the value of *G* on Saturn?
3. What is the value of *g* on Saturn at the equator? (hint: find the equatorial radius and mass on wiki or another source) (m/s^2)

The acceleration due to gravity *g* on Earth's surface is about 9.81 m/s^2

4. What is *g* as experienced by an astronaut on the ISS, orbiting at average altitude of 415km?
5. What is the mass of a 75kg astronaut on the ISS? (kg)
6. What is the weight (force) of a 75kg astronaut on the ISS? (N)

2 – Concepts in Newton's Law

Open the simulation (https://phet.colorado.edu/en/simulation/gravity-force-lab)



Check ‘Constant Size’. Set the masses of both the spheres to 500 kg and set a distance of 10 m apart
7. What is the value of the force of attraction between them?

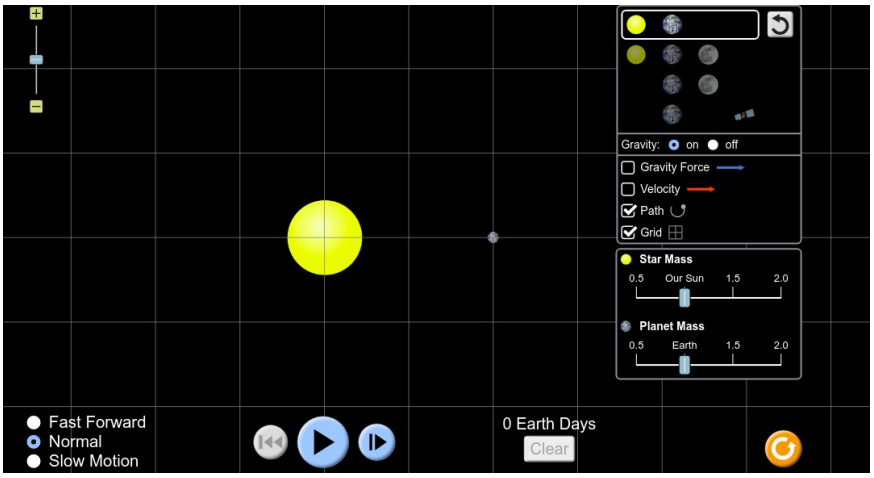
Bring the two mass as close together as possible,
8. Now increase the distance between them, what happens to the force of attraction between them?
9. If you increase one of the two masses, what happens to the force of attraction between them?

Set Mass 1 = 10 kg and Mass 2 = 20 kg
10. Which mass is pulled with the greater force?
11. Can you find a quantity in the simulation that if you vary it, would result in the force on Mass 1 being different (in the magnitude) to the force on Mass 2? If so which quantity?

12. Are the two forces a valid example of a pair of action/reaction forces?
13. What would be the force between them if the distance of separation were infinitely large?

3 – Kepler’s Laws

Open the simulation (https://phet.colorado.edu/en/simulation/gravity-and-orbits). Choose *Model*. Select the Sun and Earth system on the top of right corner. Select *path*, *grid* and *velocity* to display the data.



Run the simulation. Be careful with your observations
14. Which is the shape of orbit?
15. How does the speed of the Earth depend on its distance to the Sun?
16. Does the orbit change if you change the mass of the Earth?
17. Does the orbit change if you change the mass of the Sun?

The ‘perihelion’ is the point of the orbit where the planet is the closest to the star, the ‘aphelion’ instead is the farthest. Display also the *Gravity Force*.
18. How does the magnitude of the force change as the planet moves away from the perihelion?
19. What is the period of the Earth around the Sun?

Kepler 3rd Law relates the period of revolution T of a planet orbiting the Sun (of mass M), with its semi-major axis a

$$T^2 = \frac{4\pi^2}{GM} a^3$$

Restart, and increase the Star Mass to 1.5. Use this setting to check your answers to the questions 15. Now by looking at the simulation:
20. What is the approximate value of the period now?
21. What is the approximate ratio of the aphelion over the perihelion?
22. Use Kepler 3rd Law to calculate the semi-major axis a

Restart, again Star Mass to 1.5 and display the velocity. The initial velocity appears as a red arrow in the upward direction. You can change the initial velocity: use the mouse to move around the top of the red arrow.
Reduce by (at least) half the initial speed. Run the simulation.
23. What happens to the planet?

Restart, again Star Mass to 1.5 and display the velocity. Double the initial speed (you might have to zoom out: use vertical bar top left corner). Run the simulation.
24. What happens to the planet?
25. Is it possible to find an initial velocity (try both speed and direction) such that the planet will spiral inward toward the star and then crash on it?

4 – Mass of the Sun

Kepler 3rd Law can be used to estimate the mass of the Sun M_S

$$T^2 = \frac{4\pi^2}{GM_S} r^3$$

Where r represents the mean distance of the planet to the Sun. Go online (for example here) to find the data for the distance r and orbital period T of each planet of the solar system.
26. Would the plot of T vs r be linear?

Calculate and make a plot of T^2 vs r^3. Do a linear fit with the y-intercept to zero.
27. What is the numerical value of the slope? (kg/Nm^2)
28. What is the mass of the Sun? (kg)

The expected value is $M_S = 1.989 \times 10^{30}$ kg.
29. Calculate the % error