PLANETARY MOTION - IP Activity

The program Interactive Physics allows you to set up simulations that would be very difficult to set up in the real world. In this simulation, we’re going to look at a planet orbiting the sun or a moon/satellite around a planet. With this software you can change the initial conditions (masses, velocities, etc...) and see how they affects the system as it runs in a real time simulation. Start by loading up file PlanetaryMotion located in the T: drive. The smaller object (we will call the satellite) will be set up to orbit the larger object (we will call the central object).

Record the initial masses of both objects:
Body 1 (the satellite) Mass:____,  Body 2 (the central object) Mass:____

Press the Run button and watch the satellite begin its orbit. Press Stop and Reset and double click on the object to change its initial values. You can display the physical values to take measurements.

PART 1: MOTION and FORCE

1) Observe the shape of the orbit: You can trace the path by clicking on the tab World and then set the number of frames on Tracking. You can erase the path by clicking on Erase Track. What geometrical figure is the shape of this orbit?

2) Increase and decrease the value of central object’s mass a few times. Does the orbit change? If so, how?

3) Increase and decrease the mass of the satellite a few times. Again, remember to RESET between changes. Does the orbit change? If so, how?

4) Considering Newton’s Law of universal gravitation, comment on why the answers to #2 & #3 are different. If your answers are the same, repeat steps 2 & 3.

5) Examine the gravitational force acting on the satellite during its orbit. How does the magnitude of the gravitational force depend on the distance between the objects?
6) The acceleration due to gravity $g$ on Earth’s surface is about 9.81 m/s$^2$. Using the universal law of gravitation calculate $g$ as experienced by an astronaut on the ISS, orbiting at average altitude of 415km.

What is the weight of a 60kg astronaut on the ISS?

Why does the astronaut experience ‘weightless’ even if her weight in far from being zero?

PART 2: VELOCITY and ENERGY

7) RESET once more. Now run the simulation, and pay attention to the velocity of the satellite. How does the velocity depend on the distance between the objects?

8) Decrease the mass of the central object by a factor of one hundred (set it to $10^{10}$ kg). Run the simulation and allow the satellite to move off the screen. Let the simulation continue to run and observe the magnitude of velocity of the satellite. Did the speed increase, decrease, or remain roughly the same? Explain why.

9) RESET and set the mass of the central object to its initial value of $10^{12}$ kg. Now run the simulation, watching the kinetic energy of the satellite. How does the kinetic energy depend on the distance between the objects?

10) RESET and keep the mass of the central object at its initial value of $10^{12}$ kg. Now run the simulation, watching the potential energy of the satellite (the reported values are in the correct units of Joules but are erroneously displayed as Newtons). How does the potential energy depend on distance between the objects?

11) Calculate the total energy for the satellite. Take both the values of the kinetic energy and potential energy for two different locations in the orbit, with significantly different distances:

<table>
<thead>
<tr>
<th>Location</th>
<th>kinetic energy</th>
<th>potential energy</th>
<th>total energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How do the values of the total energy compare?
PART 3: PLANETARY SYSTEMS

JUPITER and MARS

Reset. Now imagine the central object to be the Sun, and the first satellite to be the planet Mars. Add a second planet, Jupiter, by selecting the yellow circle on the top left. Place it in an orbit around the sun, beyond Mars and change its size to be different from Mars (it’s ok to choose Jupiter smaller, we just want to track its motion and its size will not be significant). Note you can move the various measurements’ displays in order to have more room. Give Jupiter an initial velocity: click on the center of Jupiter and, while holding the mouse button, move the mouse around. This will create a velocity vector. Play with the software by giving different initial velocities. Describe the various possible outcomes you observe. You can also use the zoom in/out buttons to trace Jupiter’s motion.

Now set Jupiter’s velocity to create a stable planetary system (without collision or ‘losing’ Jupiter). You can trace the orbit using the Tracking command

12) Which planet has the greater period? Is this consistent with which Kepler law? Explain.

13) Try to set different masses for Jupiter. Does the mass of the planet affect its period? If so, is this consistent with which Kepler’s law?

14) Does the mass of the planet affect its orbit (its distance from the Sun)? If so, is this consistent with which Kepler’s law?

A COMET

Add a comet to the planetary system. To do so remove Jupiter from the simulation and simply ‘convert’ Mars into a comet placing it about five time as far from the Sun and giving it a proper initial velocity so that the eccentricity of its orbit is close to the value $e=1$. The orbital eccentricity $e$ is a parameter used to describe the geometrical shape of an orbit: $e = 0$ is a circular orbit, for the Earth $e = 0.02$, for the Halley's comet $e = 0.967$. If $e$ is greater than one, the comet will orbit the sun once and never return into the solar system. Will your comet ever come back? You could wait a long time to see, or you can calculate the total energy of your comet.

15) Calculate the total mechanical energy of the comet: the sum of the potential + kinetic energy at any one point ____________________

16) Looking at the value of the total energy above, how do you determine if your comet ever come back?
PART 4: MASS OF THE SUN

Kepler’s 3rd law of planetary motion can be used to estimate \( M_S \) the mass of the sun

\[
T^2 = \frac{4\pi^2}{GM_s} r^3
\]

Go online and find the data for the mean distance and orbital period of the planets of the solar system.

17) Enter the orbital periods of the planets (in seconds) and the mean distances (in meter) between the planets and the sun into separate columns in an Excel spreadsheet. Plot \( T \) versus \( r \) and note that the resulting plot is not linear.

18) Now calculate \( T^2 \) and \( r^3 \) in two adjacent columns (let Excel do the calculations) and plot \( T^2 \) versus \( r^3 \). Is the plot linear? Do a regression analysis and determine the slope of the plot. According to Kepler’s 3rd law,

\[
slope = \frac{4\pi^2}{GM_s} \quad M_S = \frac{4\pi^2}{G \cdot slope}
\]

19) Calculate \( M_S \) using the above formula and compare with the expected value \( M_S = 1.989 \cdot 10^{30} \) kg.

\[
M_S = \underline{\quad} \quad \%error = \frac{|\text{measured}-\text{expected}|}{|\text{expected}|} \times 100 = \underline{\quad}
\]

PART 5: NEWTON vs EINSTEIN

20) A metal block rests located on a planet’s surface as shown in the picture below. Draw the free body diagram for both the block and the planet accordantly to Newton’s theory and Einstein’s theory of gravity. Draw the forces on the objects and not on the points of contact between them. It has to be clear on which object the force is acting.

21) Venus is orbiting around the Sun, the arrow indicates the velocity vector. Draw the free body diagram for both Venus and the Sun accordantly to Newton’s theory and Einstein’s theory of gravity.

22) According to Einstein’s theory of gravity, how is the orbit of Venus explained?