Lab #6: Gravitational Acceleration

Gravity governs the motion of all the celestial bodies in the Universe, with the exception of the very rarified and hot interstellar gas (which feels magnetism as much as gravity). Gravity pulls everything down on Earth, it acts on the astronauts, it is pulling down the Moon, and it keeps Earth from escaping from the Sun into space.

It is quite remarkable that the acceleration caused by gravity is independent of the size, mass, or any other property of the body being pulled down. As counterintuitive as it seems, in the absence of air resistance, a feather and a hammer take the same time to fall down. A heavy hammer feels a stronger force of gravity but is also harder to move: the two effects exactly compensate each other. Any dropped object picks up the same speed at the end of a 1 sec long fall, about *9.81 m/s*. The gravity of Earth accelerates a dropped object by this amount of speed every second; we say that the gravitational acceleration is $9.81\ m/s^2$.

This gravitational acceleration is due to the mass of Earth. We must imagine all of the mass of Earth concentrated in its center, which is *6,378 km* away from us (under our feet). Newton's law of universal gravitation tells us that any mass pulls any other mass towards it, and the gravitational acceleration it causes is expressed by the formula

$$a = G\, M/r^2$$

where the universal gravitational constant *G* has been measured in the laboratory, with the result of $G = 6.67 \times 10^{-11}\ m^3/(kg\ sec^2)$. As you see from the formula, the gravitational acceleration depends on two things: (i) the mass of the gravitating object (Earth), and (ii) the distance from its center.

In this laboratory exercise we will measure the gravitational acceleration on the surface of Earth by dropping a ball and timing its fall, and then on the surface of the Moon by watching a video clip in which the astronauts drop objects on the Moon. We'll look for visual proof of the fact that all bodies take the same time to fall, independent of their masses. We'll use our results to calculate the masses of the Earth and Moon, and we will even be able to make a statement about the origin of the Moon!

The data we will need for this are:

- the radius of the Earth: *6,378 km*.
- the radius of the Moon: *1,738 km*.
- the average gravitational acceleration on Earth: $9.81\ m/sec^2$. (Compare with your result).
- Newton's the gravitational constant: $G = 6.67 \times 10^{-11}\ m^3/(kg\ sec^2)$.
- the distance to the Moon: *384,400 km*.

PROCEDURE AND LAB REPORT

Date:_______ Your name: ___________Partner's name: ___________ Section: ___/___

Maximum two students may work together as partners!

1. ***Read the review, and to your instructor's introduction, and answer:***

-- All astronomical objects move under the influence of gravity only, with the single exception of ____.

-- The effect of the Sun's gravity on Earth is that Earth is _________________________.

-- The strength of gravity is expressed by telling the _____________________________.

-- Newton's law of gravitation tells us that any object causes gravitational acceleration, by pulling other objects toward it, depending only on its ____ and ______________.

-- Gravitational acceleration means what _____ a dropped object picks up every second.

2. ***Drop a tennis ball from a few meters high and time with a stopwatch how long it takes to reach the ground. Try it three times. Measure the height of the fall with a string and a ruler.***

-- The ball has been dropped from __________________, which is ________*m* high.

-- The ball took the following lengths of time in the three trials: ___ *sec*, ___ *sec*, ___ *sec*.

Notice that the three values do not have to be exactly equal. There can be no measurement without an error margin! Round the numbers and keep as many digits as you can be sure are accurate. Average the three times; your result is ___ *sec*.

3. ***Calculate the average speed of the ball during the fall.*** Your result is ___ *m/sec*.

4. ***Calculate the gravitational acceleration.*** The ball is accelerating. Its average speed during the whole fall will be slower than its speed at the endpoint when it reaches the ground. You would expect (correctly) that the final speed of the ball was twice as fast as the average speed; that is, its final speed was ___ *m/sec*. This is how much speed the ball picked up during the whole time of the fall, so the gravitational acceleration has been measured to be ___ m/sec^2.

5. ***Compare this result to the theoretical value of*** $9.81\ m/sec^2$***; calculate the percent difference.*** Note that neither the theoretical nor your measured value is absolutely accurate; both have their corresponding error margins. We try to keep the errors low, but do not expect that *any measurement* can *ever* have no errors!

The percent difference is _____ %; do you think this is acceptably low? ______________.

6. ***Now watch the clip*** on the "*HammerAndFeather.mov*", which you'll find in the folder *Desktop/AstroLab/AstroDocuments.* Repeat the above measurement and calculations by timing the hammer and feather dropped by the astronaut.

-- The hammer took the following lengths of time in the three trials: ___ *sec*, ___ *sec*, ___ *sec*.

-- Your estimate of the height of the fall is ________*m*.

-- The average of the above times is ___ *sec*, the average speed is ___ *m/sec*, and the final speed is ___ *m/sec*, so the gravitational acceleration is found to be ___ m/sec^2.

7. ***From all this you conclude that (i)*** the hammer and the feather took _______ *sec* to fall down, and ***(ii)*** that the gravitational acceleration on the Moon is ____ times smaller than on Earth.
How high could you jump on the Moon? _______ *m*. A cow can certainly not jump over the Moon, but could *you* jump over a cow on the Moon? _____ .

8. ***Given the above results, calculate the average density of the Earth.***
-- The volume of Earth is $V = \frac{4\pi}{3} \times r^3$ =___________ m^3. (Convert *r* to meters first.)
-- The mass of the Earth is M = __________ *kg*. (Solve $a = G\frac{M}{r^2}$ for M; you know *a*, *G*, and *r*.)
-- The average density of Earth is $\rho = \frac{M}{V} =$ __________ kg/m^3 = ___________ g/cm^3.
-- Given that the density of water is $1\ g/cm^3$, rock is ~ 2.5 g/cm^3, and iron is 7.8 g/cm^3, what is Earth primarily composed of? ___________________

9. ***Now do the same for the Moon.***
-- The volume of the Moon is V = ___________ m^3.
-- The mass of the Moon is M = ____________ *kg*.
-- The average density of the Moon is ρ = __________ kg/m^3 = __________ g/cm^3.
-- What is the Moon primarily composed of? __________________.
The correct answer indicates that the material that became the Moon could have been thrown out of the upper layers of Earth in a collision with another planet-in-the-making when Earth was still young.

10. ***Calculate the gravitational acceleration due to Earth at the distance of the Moon and estimate how much the Moon falls in a week's time.***
-- The distance to the Moon is ______ times larger than the radius of the Earth, so the gravitational acceleration should be _______ times weaker there; that is, _______ m/sec^2.
-- A week is ________ *seconds*, so at the end of a week, the Moon picks up _________ *m/sec* of final speed. The average speed is half of this, ___________ *m/sec*, and in a week the Moon then falls _________ *m* = ___________ *km*. So, how long would it take for the Moon to fall down? About ___________.

11. ***Then, why does it not fall down? Because it also moves sideways.***
-- In a week, the Moon travels ______ of its orbit, so it moves _________ *km* sideways. That puts it on an almost circular orbit.