Laboratory 2: Gravitation & motion of the planets

Experiments are to be completed on the provided laboratory sheets below; any supporting material (eg. graphs) should be attached. Make sure your name and your partners name(s) are clearly indicated on the front page of your lab. **Neatness and clarity count!** Use complete sentences in answering all questions, explain your answers when asked clearly, and if you use an equation to do a calculation, *write the equation down* first, then put in numbers and solve. **Show all your work!**

Labs must be written *in pen* and are due a week after the lab.

APPARATUS

Metrestick (2m), stopwatch, lead & wood balls, ruler, polar coordinate graph paper (provided).

OBJECTIVE

1. To verify the *acceleration due to gravity* from theory.
2. To learn about the *motion* of some of the planets in the sky.

THEORY

1). If dropped from rest, the distance fallen d is related to the fall time t and acceleration a by

$$d = \frac{1}{2}at^2$$

If we measure d and t we can solve for the acceleration, a:

$$a = \frac{2d}{t^2} \tag{1}$$

2). From Newton's Law of Gravitation, the predicted ***gravitational acceleration*** on the Earth is

$$g = G\frac{M_e}{r^2} \tag{2}$$

where $G = 6.67 \times 10^{-11}$ N m^2/kg^2 is the *Universal Gravitational Constant*. At the Earth's surface, use Earth's mass ($M_e = 5.974 \times 10^{24}$ kg) and Earth's radius ($r = 6.37 \times 10^6$ m).

3). To compare two experimental values use *percent difference*:

$$\text{Percent Difference} = \frac{(high - low)}{average} \times 100 \tag{3}$$

(Example) *We measure two values to be 1.5 and 1.7 units; comparing them,*

$$\text{Percent Difference} \;=\; \frac{(high - low)}{average} \times 100 \;=\; \frac{(1.7 - 1.5)}{1.6} \times 100 \;=\; 12.5\%$$

The two values differ from each other by nearly 13%.

4). To compare a measurement with an expected value, use *percent deviation*:

$$\text{Percent Deviation} \;=\; \frac{(experimental - expected)}{expected} \times 100 \tag{4}$$

(Example) *We measure a value to be 9.0 units and compare to a known, expected value of 10.0:*

$$\text{Percent Deviation} \;=\; \frac{(experimental - expected)}{expected} \times 100 \;=\; \frac{(9.0 - 10.0)}{10.0} \times 100 \;=\; -10\%$$

The measured value is ten percent below the expected value.

5). Figure 1 shows the orbit of the Earth (E) about the Sun (S). Also shown are orbits for a planet closer to the Sun than the Earth (an *inferior planet*) and further from the Sun (a *superior planet*). As planets orbit the Sun at different rates, they periodically align with the Earth and Sun. For an *inferior planet*, important alignments are *inferior conjunction* (IC) and *superior conjunction* (SC). For a *superior planet*, important alignments are *conjunction* (C) and *opposition* (O). **NOTE:** *during these alignments, the planet, Earth and Sun align exactly in a straight line.*

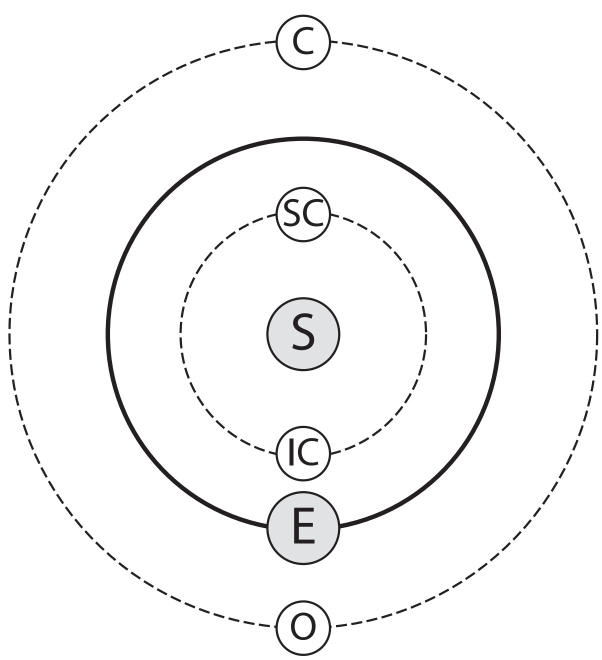

Figure 1: Important planetary alignments.

Mark this lab: ☐ individually ☐ as a group NAME: PARTNER:

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Part A: acceleration due to gravity

1. Form into groups of four (4). Take the stopwatch, metresticks and balls out onto the second floor balcony of the building. Several members (with stopwatch) should go down to ground level while the rest remain on the balcony with the lead and wood balls.

2. [***1 mark***] Pick a single, consistent dropping position. Use the (2m) ruler to **measure the height to the ground (in meters)** from where the ball will be released: ____________ m.

3. [***1 mark***] Which ball do you *think* should fall *faster* (take less time)? Why?

4. [***1 mark***] Do 5 drops of each ball. Practice dropping & timing to get CONSISTENT fall times for a given ball. Be sure NOT to anticipate starts/stops - time the ENTIRE fall - and redo drops that vary *significantly* from 'typical' times. **Record the time of fall (in seconds)** for each drop:

	Time of fall (s)					Average
Lead						
Wood						

Calculate the *average time of fall* (in seconds) for **each** ball and enter it in the table above.

5. [***1 mark***] Use Equation (1), the *height* (in meters) and the *average time of fall* (in seconds) **to calculate the *acceleration*** 'a' (in meters/second^2) for **EACH** ball, below. Show ALL work.

6. [*2 marks*] **Put your group's values for the acceleration of the balls on the board and in the table below**. Your instructor will calculate the *class average accelerations* of each.

	Acceleration (m/s^2)										Class Average
Lead											
Wood											

Use Equation (3) to calculate the percent difference between the class average accelerations of the lead and wood balls and comment on the result (e.g. *similar?*).

7. [*2 marks*] **Calculate the *expected* acceleration g (in m/s^2) using Equation (2). Compare this (*expected*) value of g to the (*experimental*) class average acceleration of the lead ball using Equation (4). Repeat, comparing the (*expected*) acceleration g and the (*experimental*) class average acceleration of the wood ball. Comment** (e.g. *similar?*).

8. [***1 mark***] Can we conclude that the two balls fell at the same rate (i.e. with the same acceleration) within experimental error? To answer this, consider whether the ***difference*** **between the balls' *measured* accelerations (Q6) is *significant* given the amount of experimental error in this lab** (which is indicated by *their deviations from the expected value of g* **(Q7)**).

Part B: planetary motion

1. [***2 marks***] **** WATCH the video instructions on the website. **** Using the polar graph paper provided on the website, ***CAREFULLY*** **plot the positions of Venus, Earth and Mars** on your graph using the data provided in Tables 1 & 2. **Label each planets' position** when you plot it, eg. M1, E1, V1, M2, E2, V2, etc.

	Heliocentric Longitude, °		
Location	Venus	Earth	Mars
1	280	270	310
2	325	300	324
3	18	330	338
4	68	0	352
5	115	30	6
6	165	60	20
7	213	90	34

Table 1: Orbital positions for Venus, Earth and Mars.

Mean orbital radius (AU)		
Venus	Earth	Mars
0.72	1.00	1.50

Table 2: Orbital radii for Venus, Earth and Mars.

2. [***1 mark***] Venus is *NOT* at *inferior conjunction* or *superior conjunction* during this period; however, it *does* achieve ONE of these shortly AFTER position 7. **Which one? Explain.**

3. [***1 mark***] Examine the motions of Earth & Mars along their orbits. **Does Mars achieve *conjunction* or *opposition* during this period? If so, approximately when? Explain.**

4. [***1 mark***] Use a ruler & pencil to draw a line ***FROM*** Earth at position 1 ***TO*** Venus at position 1, continuing the line **all the way to the edge of the paper**. **Put a labelled dot (eg. V1) at the END of the line**; this approximates the position of Venus against distant stars. **Repeat** for positions 2 - 4. **Viewed from Earth, is Venus in *retrograde* in this period? Explain.**

5. [***1 mark***] **Repeat Question 4 for *ALL* 7 POSITIONS of Mars**; use labeled dots, eg. M1.

6. [***1 mark***] Measure the radial distance between the Sun and Earth's orbit: __________ cm. This corresponds to 1 AU or 1.496×10^8 km. **Calculate the scale of the graph in km-per-cm.**

7. [***1.5 marks***] Measure the distance between Earth and Mars at position 1: ________ cm. **Multiply this by the scale you found in the previous question to convert this distance to km. Given the diameter of Mars $d_{Mars} = 6794$ km, use the angular size equation of Lab 1 to determine Mars' angular size in degrees as viewed from Earth at this time.**

8. [***1.5 marks***] Measure the distance between Earth and Mars at position 4: ________ cm. **Repeat the above to determine Mars' angular size in degrees from Earth at this time.**

9. [***1 mark***] **Would it be better to observe Mars at position 1 or 4? Justify your answer.**