Physics 20IB: Accelerated Motion in Free-fall Lab

Design:

Problem:

- What are the effects of surface area in acceleration due to gravity?

Experimental Design:

- This lab will test the effects of the surface area factor on acceleration due to gravity. Pieces of paper will be dropped down and timed from high point of release, where the release point will be constant to reduce human timing/reaction errors. The paper will be folded proportionally (always half of the previous) to manipulate the surface area; five trials will be recorded - four of the closest results will be put into use as data for this lab.

Hypothesis:

- The time of descent of the paper will get faster as the surface area of the paper decrease. The increase and decrease in the time of descent should be caused by natural factors such as air resistance acting towards the surface area of the paper in the test environment.

Variables:

- **Manipulated Variable: Surface Area**

  The surface area of the paper will be measured with a ruler before each trial takes place. The surface area will always be measured to the nearest 0.01cm by using a ruler measuring in millimeters and converting it back to centimeters.

- **Responding Variable: Time of Descent**

  The paper will be dropped with the help of a partner on top of the apparatus at a constant vertical displacement and position (the paper will be dropped horizontally against its surface area). The partner at the bottom of the apparatus will be timing the time of descent of the paper using an electronic stop watch measuring to the nearest 0.01s by reacting to the very first sound of the paper hitting the ground.

- **Controlled Variable(s): Vertical Displacement; Environmental Conditions; Launch Velocity/Position; Mass of Test Subject**

  The launch velocity will be controlled by the help of a partner on the top of the apparatus (V_i=0) by carefully releasing every piece of the paper against its widest surface area against the air in the same manner every trial so that no extra force is given to the paper before its point of release which may alter its initial velocity. The environmental conditions of the experiment will be controlled by performing all trials in the same hallway with no excess air flow to possibly alter or effect the time of descent of the paper. The temperature of the test environment will also remain constant, which should help maintain a consistent amount of air resistance that the paper will encounter. The vertical displacement will remain constant at 520.0cm because it will help maintain the time of descent to surface area ratio at a constant throughout the experiment, which will help to answer the problem of this experiment later in the lab report. The mass of the paper used to test will remain with a constant mass to proportionalize the surface area to mass ratio, which will help to compare the final results.

Materials

- Standard Testing Stop Watch (Measured to the Nearest 0.01s)
- Standard Measuring Tape (Measured to the Nearest 0.1 cm)
- Ruled Sheets of Paper by Media Inc.

Diagram:

Procedure

* The following procedure will be performed after every transformed surface area.

1. The folded pieces of paper will be dropped from a constant height, in order to minimize the human reaction error when timing the time of descent, the height in which the paper will be released will be relatively high(520.0cms).
2. The paper will be dropped at a constant position and launch velocity, it will be placed flat against its largest surface area, we want to do this because we are constantly changing the surface area and observing its effects in relations to time
3. A partner at the top of the apparatus will drop the paper down at the count of 3 from the partner below the apparatus, as the partner below the apparatus will start the stop watch.
4. As soon as the partner below hears the sound of the paper hitting the floor, he will stop the stop watch and record the time of descent of the paper.
5. The person below the apparatus will record data after each trial; a total of 5 trials will be recorded for every change in surface area.

End of Design Section

Data Collection and Processing

1. **Paper-Time Data Table:**

Trials*:	1	2	3	4	5	Average[&]
Paper Size[#]:Full	6.00s	6.00s	6.39s	6.58s	6.27s	6.25s
Paper Size:1/2	4.52s	4.57s	4.80s	4.93s	4.62s	4.69s
Paper Size:1/4	3.69s	3.46s	3.30s	3.88s	3.73s	3.61s
Paper Size:1/8	2.08s	2.46s	2.39s	2.31s	2.25s	2.30s

& Average (Time) = $\frac{\text{Sum of Results of Trials}}{\text{Number of Trials}}$

Paper Size Uncertainties are stated in the Data Table (#2) below.

* Trials are measured in relation to time in seconds, Stop Watch Uncertainty: ±0.01s and Reaction Time Uncertainty (Determined by equation):

$$\text{Average} = \frac{\text{higest value} - \text{lowest value}}{2}$$

- Trial 1: $\frac{6.58-6.00}{2} = 0.29s$
- Trial 2: $\frac{4.93-4.52}{2} = 0.21s$
- Trial 3: $\frac{3.88-3.30}{2} = 0.29s$
- Trial 4: $\frac{2.46-2.08}{2} = 0.19s$

On Average:

$$\frac{0.29s+0.21s+0.29s+0.19s}{4} = 0.245s$$

=0.25s

Final Uncertainty For Average Time:

- 0.25s + 0.1s = **±0.35s**

2. **Surface Area of Paper Data Table:**

Paper Size	Full	1/2	1/4	1/8
Width(cm) ±0.05cm	21.30	21.30	10.65	10.65
Height(cm) ±0.05cm	27.40	13.70	13.70	6.85
Surface Area(cm^2)	583.62±2.44	291.81±1.90	145.91±1.22	72.95±0.87

* The surface area is measured to the nearest 0.01cm by a ruler measuring in millimeters and then converting to centimeters, each width and height are measured manually.

Propagation of Uncertainties for Surface Area of Paper:

- Paper Size - Full:
  - Dimensions: $21.3\text{cm} \pm 0.05\text{cm} \times 27.4\text{cm} \pm 0.05\text{cm}$
  - Percent Uncertainty for each $\frac{0.05\text{cm}}{21.3\text{cm}} \times 100\%$=0.234…% and

    $\frac{0.05\text{cm}}{27.4\text{cm}} \times 100\%$=0.182…%
  - Values multiplied and Percent Uncertainty added

    $21.3\text{cm} \times 27.4\text{cm}$=583.62cm^2 and 0.235%+0.182%=0.417%
  - Final Absolute Uncertainty: $583.62\text{cm}^2 \times \frac{0.417}{100} = 2.44\text{cm}^2$
- Paper Size - 1/2 Of Original Paper:
  - Dimensions: $21.3\text{cm} \pm 0.05\text{cm} \times 13.7\text{cm} \pm 0.05\text{cm}$
  - Percent Uncertainty for each $\frac{0.05\text{cm}}{21.3\text{cm}} \times 100\%$=0.234…% and

    $\frac{0.05\text{cm}}{13.7\text{cm}} \times 100\%$=0.365…%
  - Values multiplied and Percent Uncertainty added

    $21.3\text{cm} \times 13.7\text{cm}$=291.81cm^2 and 0.235%+0.365%=0.652%
  - Final Absolute Uncertainty: $291.81\text{cm}^2 \times \frac{0.652}{100} = 1.90\text{cm}^2$
- Paper Size - 1/4 Of Original Paper:
  - Dimensions: $10.65\text{cm} \pm 0.05\text{cm} \times 13.7\text{cm} \pm 0.05\text{cm}$
  - Percent Uncertainty for each $\frac{0.05\text{cm}}{10.65\text{cm}} \times 100\%$=0.469…% and

    $\frac{0.05\text{cm}}{13.70\text{cm}} \times 100\%$=0.365…%
  - Values multiplied and Percent Uncertainty added

    $10.65\text{cm} \times 13.7\text{cm}$=145.91cm^2 and 0.469%+0.365%=0.834%

- Final Absolute Uncertainty: $145.91cm^2 \times \frac{0.834}{100} = 1.22cm^2$

- Paper Size - 1/8 Of Original Paper:
  - Dimensions: $10.65cm \pm 0.05cm \times 6.85cm \pm 0.05cm$
  - Percent Uncertainty for each $\frac{0.05cm}{10.65cm} \times 100\%$=0.469…% and

    $\frac{0.05cm}{6.85cm} \times 100\%$=0.730…%
  - Values multiplied and Percent Uncertainty added

    $10.65cm \times 13.7cm$=72.95cm^2 and 0.469%+0.365%=1.199%
  - Final Absolute Uncertainty: $72.95cm^2 \times \frac{1.199}{100} = 0.87cm^2$

3. Average Time – Paper Size Data Table:

Paper Size:	Average Time of Descent $\pm$0.35s
1 Full Paper (583.62cm^2±2.44cm^2)	6.25s
1/2 Of Origin Paper (291.81cm^2±1.90cm^2)	4.69s
1/4 Of Origin Paper(145.91cm^2±1.22cm^2)	3.61s
1/8 Of Origin Paper(72.95cm^2±0.87cm^2)	2.30s

4. Theoretical Average Time – Paper Size Data Table:

*Assumed tested in a perfect vacuum, mass would not matter became there will be no external forces interacting with the paper

Paper Size:	Time of Descent
1 Full Paper (583.62cm^2±2.44cm^2)	**1.03s**
1/2 Of Origin Paper (291.81cm^2±1.90cm^2)	**1.03s**
1/4 Of Origin Paper(145.91cm^2±1.22cm^2)	**1.03s**
1/8 Of Origin Paper(72.95cm^2±0.87cm^2)	**1.03s**

Calculations:

Acceleration due to gravity: -9.81m/s^2

Formula To Calculate Final Velocity of Paper: $Vf^2 = Vi^2 + 2ad$

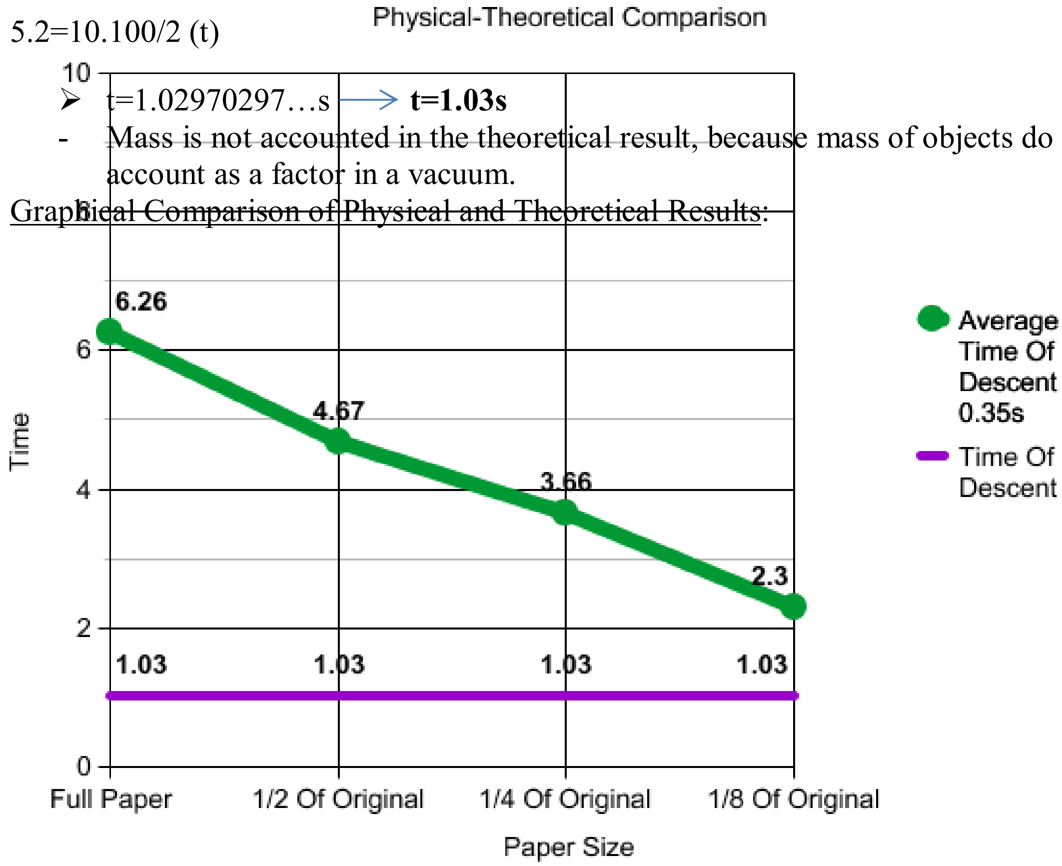
$V_f = \sqrt{0 + 2(-9.81)(5.20)}$ = 10.100….m/s

Time Used For Paper to Drop from 520cm (5.20m): d = $\left(\frac{Vf+Vi}{2}\right)t$

5.2=10.100/2 (t)

- ➢ t=1.02970297…s ⟶ **t=1.03s**
- Mass is not accounted in the theoretical result, because mass of objects do not account as a factor in a vacuum.

<u>Graphical Comparison of Physical and Theoretical Results:</u>



5. Trends from the Comparison of Physical and Theoretical:

Results	Physical	Theoretical	Difference*	Ratio&
Size: Full	6.26s	1.03s	5.23	6.08
Size: 1/2	4.67s	1.03s	3.64	4.53
Size: 1/4	3.66s	1.03s	2.63	3.55
Size: 1/8	2.30s	1.03s	1.27	2.23

- Time Uncertainty: ±0.01s and Reaction time: 0.25s

*Difference = Physical Value – Theoretical Value

&Ratio = Physical Value: Theoretical Value

<u>Percent Error Calculations:</u>

$$Size: Full: \frac{6.26s - 1.03s}{1.03s} \times 100\% = 507.76699 \ldots \%$$

$$Size: 1/2: \frac{4.67s - 1.03s}{1.03s} \times 100\% = 353.39805 \ldots \%$$
$$Size: 1/4: \frac{3.66s - 1.03s}{1.03s} \times 100\% = 255.33980 \ldots \%$$
$$Size: 1/8: \frac{2.30s - 1.03s}{1.03s} \times 100\% = 123.30097 \ldots \%$$

On average the difference of seconds between each folded surface area from previous is:

$$\frac{(6.26s - 4.67s) + (4.67s - 3.66s) + (3.66s - 2.30s)}{4} = 0.99s$$

6. Acceleration due to Gravity:

Paper	Experimental Acceleration	Theoretical Value	Percent Error (Calc. Below)
Size: Full	$-1.61\ m/s^2$	$-9.81\ m/s^2$	83.58%
Size: 1/2	$-2.16\ m/s^2$	$-9.81\ m/s^2$	77.98%
Size: 1/4	$-2.76\ m/s^2$	$-9.81\ m/s^2$	71.87%
Size: 1/8	$-4.39\ m/s^2$	$-9.81\ m/s^2$	55.25%

Calculations:

Experimental Acceleration:

- Formula $a_{ave} = \frac{Vf - Vi}{t}$, $Vf^2 = Vi^2 + 2ad$

$$V_f = \sqrt{0 + 2(-9.81)(5.20)} = 10.100\ldots m/s \quad V_f = -10.10\ m/s$$

1. $\frac{10.100 m/s}{6.26s} = -1.61\ m/s^2$
2. $\frac{10.100 m/s}{4.67s} = -2.16\ m/s^2$
3. $\frac{10.100 m/s}{3.66s} = -2.76\ m/s^2$
4. $\frac{10.100 m/s}{2.30s} = -4.39\ m/s^2$

Percent Errors (Experimental Acceleration to Theoretical Value, $-9.81\ m/s^2$):

$$\frac{((1.61 m/s^2) - (9.81 m/s^2))}{9.81 m/s^2} = 83.58\%$$

$$\frac{((2.16 m/s^2) - (9.81 m/s^2))}{9.81 m/s^2} = 77.98\%$$

$$\frac{((2.76 m/s^2) - (9.81 m/s^2))}{9.81 m/s^2} = 71.87\%$$

$$\frac{((4.39 m/s^2) - (9.81 m/s^2))}{9.81 m/s^2} = 55.25\%$$

End of Data Processing Section

Conclusion and Evaluation

Conclusion

The purpose of this accelerated motion lab in free-fall experiment was to investigate acceleration due to gravity and the factors that affect it. According to my calculations, this experiment's end result does agree with my hypothesis, which proves that the surface area of an object does affect its time of descent. On average, for every fold of the paper (which cuts the surface area to half of its previous) it takes around 0.99s less to hit the ground than the surface area on the previous paper.

Based on the data calculated, if a true free-fall does happen to the paper, which means that there will be no air resistance or any other natural forces affecting its flight with environments similar to a vacuum, the paper, regardless of mass should hit the ground from a height of 520cm (5.2m) in approximately 1.03s. Since the investigations of the factors that effects the acceleration of an object due to gravity is a requirement for this lab, percent errors of results are needed to put into consideration. According to my calculations, the percent error of the experimental time of descent to the perfect free fall, ranged from +123.30097…% all the way up to +507.76699…%, and the experimental acceleration compared to the theoretical acceleration (-9.81m/s) has a percent error that ranges from 55.25% to 83.58%. What could have caused such a great difference between the theoretical and the experimental results? Although there are two noteworthy uncertainties in the calculations- the surface area uncertainty which ranged from 0.87cm^2 to 2.44cm^2, the time uncertainty and reaction time uncertainty may have at most put us 0.30s (±0.01s of instrumental error and 0.25s reaction time error) these uncertainties are fairly small in terms of the percent errors, it shouldn't cause such a great differences approximating 500%... unless we account the external factors in the test environment, since earth is not a vacuum, things such as free-fall cannot happen under normal circumstances, I theorize that the two main factors that affected my results may have come from air resistance and atmospheric pressure, as air hits the paper in a unpredictable pattern and depending on the atmosphere pressure, an object may fall faster or slower due to the density of the air.

Evaluation of Experimental Procedure

Since the materials used for this experiment was limited, my partner and I decided to make use of the large school supplies we had, lined paper to use for this experiment. There is nothing wrong with the lined paper, but there are three holes at the left side of each paper, this may have created some errors in the results of the first trial as air can pass through the holes altering its time of descent, this did not affect the other trials because once the paper was folded, the holes were covered. The second error that may have occurred also comes from the paper, since the paper are folded half by hand and drop, there is a very good chance that the paper can unfold itself on its way of descent. Thirdly, the angle of descent or drop angle could have been altered on each trial, although we tried to drop the paper at a constant height and angle, it was nearly impossible to perform the perfect drop by hand, this could have easily affected the timed result because the air can hit the paper on different angles therefore alter its path of the paper and create an error in the result. Last but not least, I felt that the location that my partner and I chose to do this experiment could have been better, because of the high point of release of the paper, the paper swirled around in the air and hit the surrounding walls, creating an error in the timing.

Improvement to Experimental Procedure

The first problem presented in the evaluation of procedure could have easily been fixed with the access to printer paper at the school, the printer papers would have resulted a more accurate time because there will be no holes in them. The second problem could have been solved by simply adding a piece of tape on the paper to prevent the unfolding during its air time, we would also improve this step by keeping the mass of the tape ±0.01g to keep a constant mass. The third and fourth problem presented in the evaluation of procedures can be summarized as one, the third problem could be very difficult to solve based on the limited equipment we have, but I believe the best solution to this problem is to perform the experiment in a "closed" system, meaning that it's done inside a controlled environment, the area, air flow and pressure will remain the same, this test apparatus can be found at the back of the school's science lab where students usually perform their chemistry experiments, I would add a support stand at the bottom where I can place the paper at a perfect angle parallel to the ground then release it quickly to start timing, this “closed” system would also solve the problem of the paper hitting the wall and give a more accurate over all time result.