Physics 1 Lab

Density measurement using Archimedes' method and reaction time measurement

Physics Department

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Lab 2

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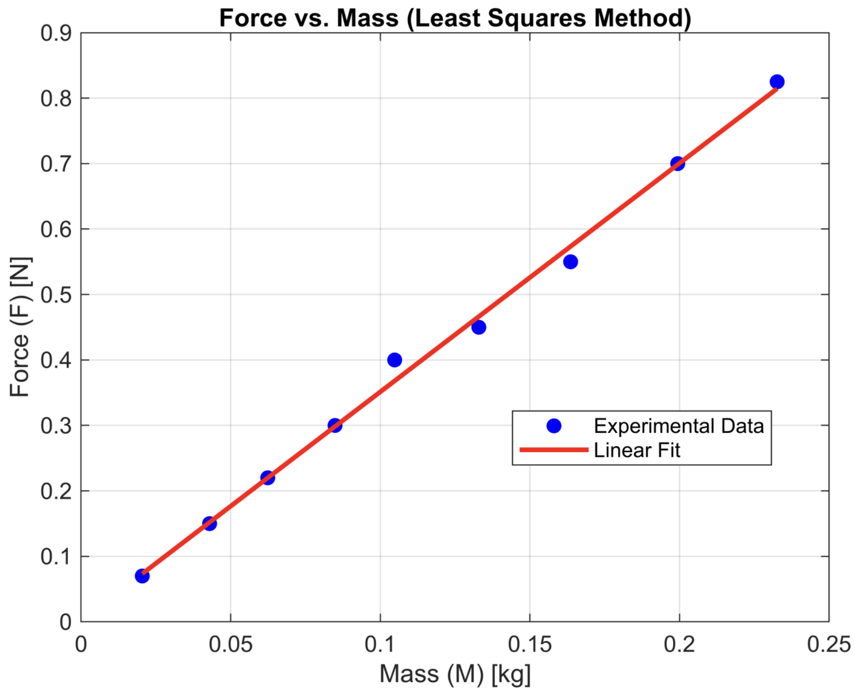
Density measurement using Archimedes' method

Question 1

Plot the graph of M versus F, determine the **slope** and **y-intercept** using the least squares method.

Answer

```
T1 = [0.2 0.42 0.61 0.83 1.025 1.300 1.600 1.950 2.275 ];
T2 = [0.13 0.27 0.39 0.53 0.625 0.850 1.050 1.250 1.450];

% Calculate Force F as the difference between T1 and T2
M = T1/9.78;
F = T1 - T2;

% Perform linear regression (least squares method) for F vs. M
p = polyfit(M, F, 1);   % p(1) is the slope, p(2) is the intercept

% Generate fitted values based on the linear model
F_fit = polyval(p, M);

figure;
plot(M, F, 'bo', 'MarkerFaceColor', 'b'); % Data points (blue circles)
hold on;
plot(M, F_fit, 'r-', 'LineWidth', 2); % Fitted line (red)
xlabel('Mass (M) [kg]');
ylabel('Force (F) [N]');
title('Force vs. Mass (Least Squares Method)');
legend('Experimental Data', 'Linear Fit', 'Location', 'best');
grid on;

fprintf('Linear Fit Equation: F = %.2f*M + %.2f\n', p(1), p(2));

y_fit = polyval(p, M);
SS_tot = sum((F - mean(F)).^2);
SS_res = sum((F - y_fit).^2);
R2 = 1 - (SS_res / SS_tot);
fprintf('R-squared: %.4f\n', R2);
```



Linear Fit Equation:
$F = 3.49M + 0.00$

R-squared: 0.9961

Question 2

Calculate the **density slope** of the metal.

Answer

```
rho_water = 1003.5;   % Density of water in kg/m^3
g = 9.81;             % Gravitational acceleration in m/s^2

T1 = [0.2 0.42 0.61 0.83 1.025 1.300 1.600 1.950 2.275 ];
T2 = [0.13 0.27 0.39 0.53 0.625 0.850 1.050 1.250 1.450];

M = T1/9.78;

F = T1 - T2;

% Perform linear regression (least squares method) for F vs. M
p = polyfit(M, F, 1);   % p(1) is the slope, p(2) is the intercept

slope = p(1);

rho_metal = (rho_water * g) / slope;

fprintf('The slope of the (F - M) line: %.4f\n', slope);

```

```
fprintf('The calculated metal density (rho_metal) is: %.4f kg/m^3\n',
    rho_metal);
```

The slope of the (F - M) line: 3.4934
Calculated metal density: 2817.9446 kg/m^3

Question 3

Explain the significance of the **regression coefficient** and interpret how well the graph fits.

Answer

The **regression coefficient** (slope) of the line represents the rate of change of the dependent variable (force F) with respect to the independent variable (mass M) in your experiment.

Mathematically, the regression equation is:

$$F = \text{slope} \times M + \text{intercept}$$

The slope tells you how much F increases (or decreases) when M increases by one unit.

Interpretation:

- A **positive slope** indicates that as the mass M increases, the force F also increases. This suggests a *directly proportional* relationship between the two variables, possibly due to the material or experimental setup.
- A **negative slope** would suggest an *inverse relationship*, meaning that as mass increases, the force decreases.
- The **magnitude** of the slope tells you the strength of this relationship. A larger value means that even small changes in mass lead to larger changes in force.

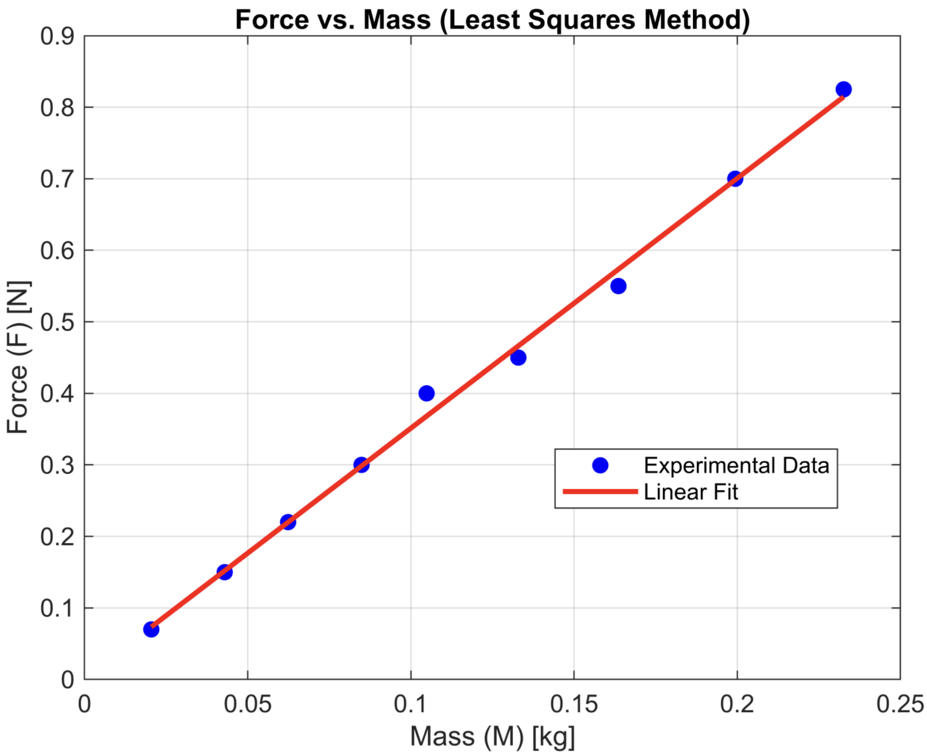
Example:

If the regression coefficient (slope) of your model is 0.5, then for every 1 kg increase in mass M, the force F would increase by 0.5 N. The units of the slope are important because they represent the *rate of change* (in this case, N/kg, Newtons per kilogram).

This provides a clear and direct understanding of how mass influences force in your experiment, based on the **linear model**.

```
F = T1 - T2;

p = polyfit(M, F, 1);    % p(1) is the slope, p(2) is the intercept

% Extract slope from the linear regression
slope = p(1);
intercept = p(2);

% Generate fitted values based on the linear model
F_fit = polyval(p, M);
```

```

figure;
plot(M, F, 'bo', 'MarkerFaceColor', 'b'); % Data points (blue circles)
hold on;
plot(M, F_fit, 'r-', 'LineWidth', 2); % Fitted line (red)
xlabel('Mass (M) [kg]');
ylabel('Force (F) [N]');
title('Force vs. Mass (Least Squares Method)');
legend('Experimental Data', 'Linear Fit', 'Location', 'best');
grid on;

fprintf('Linear Fit Equation: F = %.2f*M + %.2f\n', slope, intercept);

fprintf('The regression coefficient (slope) is %.2f.\n', slope);

if slope > 0
    fprintf('This indicates a positive relationship: as mass (M) increases, force (F) increases.\n');
else
    fprintf('This indicates a negative relationship: as mass (M) increases, force (F) decreases.\n');
end
```



Linear Fit Equation: $F = 3.49M + 0.00$ **Regression Coefficient (Slope):** 3.49

This indicates a positive relationship: as mass (M) increases, force (F) increases.

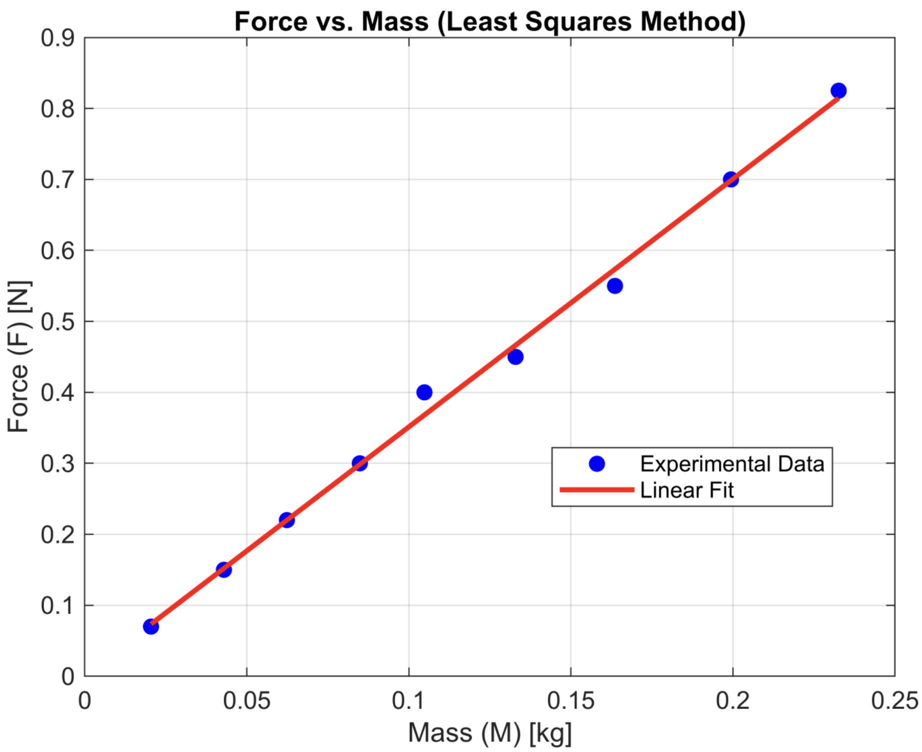
Question 4

Using the **slope and its uncertainty**, determine the **error in measuring the metal density**.

Answer

$$\text{error in slope} = \sqrt{\frac{\sum(y - y_{\text{fit}})^2}{n-2}} \cdot \frac{1}{\sqrt{\sum(x-\bar{x})^2}}$$

```
% Perform linear regression (least squares method) for F vs. M
[p, S] = polyfit(M, F, 1);   % p(1) is the slope, p(2) is the intercept, S
    is the structure with the error info

% Extract slope and intercept from the linear regression
slope = p(1);
intercept = p(2);

% Get the standard error of the slope and intercept from the structure S
slope_error = sqrt(S.normr^2 / (length(M) - 2)) * sqrt(1 / sum((M - mean(M))
    .^2));

% Generate fitted values based on the linear model
F_fit = polyval(p, M);

figure;
plot(M, F, 'bo', 'MarkerFaceColor', 'b'); % Data points (blue circles)
hold on;
plot(M, F_fit, 'r-', 'LineWidth', 2); % Fitted line (red)
xlabel('Mass (M) [kg]');
ylabel('Force (F) [N]');
title('Force vs. Mass (Least Squares Method)');
legend('Experimental Data', 'Linear Fit', 'Location', 'best');
grid on;

% Display the linear regression parameters (slope, intercept, and their
    errors)
fprintf('Linear Fit Equation: F = %.2f*M + %.2f\n', slope, intercept);

fprintf('Slope error: %.4f\n', slope_error);
```



Linear Fit Equation: $F = 3.49M + 0.00$

Slope Error: 0.0822

Question 5

Compare the **intercept error** obtained from the graph with the calculated value.

Answer

```
[p, S] = polyfit(M, F, 1);   % p(1) is the slope, p(2) is the intercept, S is the structure with the error info

% Extract slope and intercept from the linear regression
slope = p(1);
intercept = p(2);

% Get the standard error of the slope and intercept from the structure S
slope_error = sqrt(S.normr^2 / (length(M) - 2)) * sqrt(1 / sum((M - mean(M)).^2));

% Suppose you have an expected error value, replace this with the actual value:
expected_error =0.02;  % Set expected error here

fprintf('Linear Fit Equation: F = %.2f*M + %.2f\n', slope, intercept);

```

```
fprintf('Slope error from regression: %.4f\n', slope_error);

error_difference = abs(slope_error - expected_error);
fprintf('Difference between calculated error and expected error: %.4f\n',
    error_difference);

if error_difference < 0.1
    fprintf('The error is within the acceptable range.\n');
else
    fprintf('The error is outside the acceptable range.\n');
end
```

Linear Fit Equation: $F = 3.49M + 0.00$

Slope Error from Regression: 0.0822

Difference Between Calculated and Expected Error: 0.0622

Conclusion: The error is within the acceptable range.

Reaction time measurement of a person

Question 1, Question 2

Plot the distribution for the given data based on tables **H2** and **H3**.

Calculate the **standard deviation** and **mean** for tables **H2** and **H3**, and explain their significance. (You may also use curve-fitting software such as *TableCurve, Origin, SigmaPlot*.)

Answer for Question 1,2

```
time_H2 = [199 185 465 167 172 245 387 401 10 132 180 162 204 15 127 4 183
    162 220 119]; % Time delays for H2 (Alireza.H)
time_H3 = [165 215 156 186 293 267 189 192 69 75 181 410 6 179 186 175 25
    350 184 159]; % Time delays for H3 (Parsa.H)

table_H2 = table((1:length(time_H2))', time_H2', 'VariableNames', {'try', '
    Time_H2'});
disp('Table for H2:');

disp(table_H2);

table_H3 = table((1:length(time_H3))', time_H3', 'VariableNames', {'try', '
    Time_H3'});
disp('Table for H3:');

disp(table_H3);

mean_H2 = mean(time_H2);
std_H2 = std(time_H2);
fprintf('For H2 Group:\n');

fprintf('Mean response time: %.2f ms\n', mean_H2);

fprintf('Standard deviation: %.2f ms\n', std_H2);

% Basic Statistical Analysis for H3 Group
mean_H3 = mean(time_H3);
std_H3 = std(time_H3);
fprintf('For H3 Group:\n');

fprintf('Mean response time: %.2f ms\n', mean_H3);

fprintf('Standard deviation: %.2f ms\n', std_H3);

figure;
subplot(2,1,1);
plot(1:length(time_H2), time_H2, 'bo-', 'LineWidth', 2, 'MarkerSize', 8);
title('Response Time for H2 Group');
xlabel('try');
ylabel('Time Delay (ms)');
grid on;

subplot(2,1,2);
```

```
plot(1:length(time_H3), time_H3, 'ro-', 'LineWidth', 2, 'MarkerSize', 8);
title('Response Time for H3 Group');
xlabel('try');
ylabel('Time Delay (ms)');
grid on;

figure;
subplot(2,1,1);
histogram(time_H2, 'BinWidth', 10, 'FaceColor', 'b', 'EdgeColor', 'k', '
    Normalization', 'pdf');
hold on;
% Fit a normal distribution to the data
pd_H2 = fitdist(time_H2', 'Normal');
x_H2 = linspace(min(time_H2), max(time_H2), 100);
y_H2 = pdf(pd_H2, x_H2);
plot(x_H2, y_H2, 'r-', 'LineWidth', 2); % Plot fitted PDF
title('Histogram and Normal Fit for H2');
xlabel('Time Delay (ms)');
ylabel('Probability Density');
grid on;
hold off;


subplot(2,1,2);
histogram(time_H3, 'BinWidth', 10, 'FaceColor', 'r', 'EdgeColor', 'k', '
    Normalization', 'pdf');
hold on;

pd_H3 = fitdist(time_H3', 'Normal');
x_H3 = linspace(min(time_H3), max(time_H3), 100);
y_H3 = pdf(pd_H3, x_H3);
plot(x_H3, y_H3, 'b-', 'LineWidth', 2); % Plot fitted PDF
title('Histogram and Normal Fit for H3');
xlabel('Time Delay (ms)');
ylabel('Probability Density');
grid on;
hold off;
```

try	Time_H2
1	199
2	185
3	465
4	167
5	172
6	245
7	387
8	401
9	10
10	132
11	180
12	162
13	204
14	15
15	127
16	4
17	183
18	162
19	220
20	119

Table 1: Response Time Data for H2

try	Time_H3
1	165
2	215
3	156
4	186
5	293
6	267
7	189
8	192
9	69
10	75
11	181
12	410
13	6
14	179
15	186
16	175
17	25
18	350
19	184
20	159

Table 2: Response Time Data for H3

For H2 Group:
Mean response time: 186.95 ms
Standard deviation: 120.43 ms

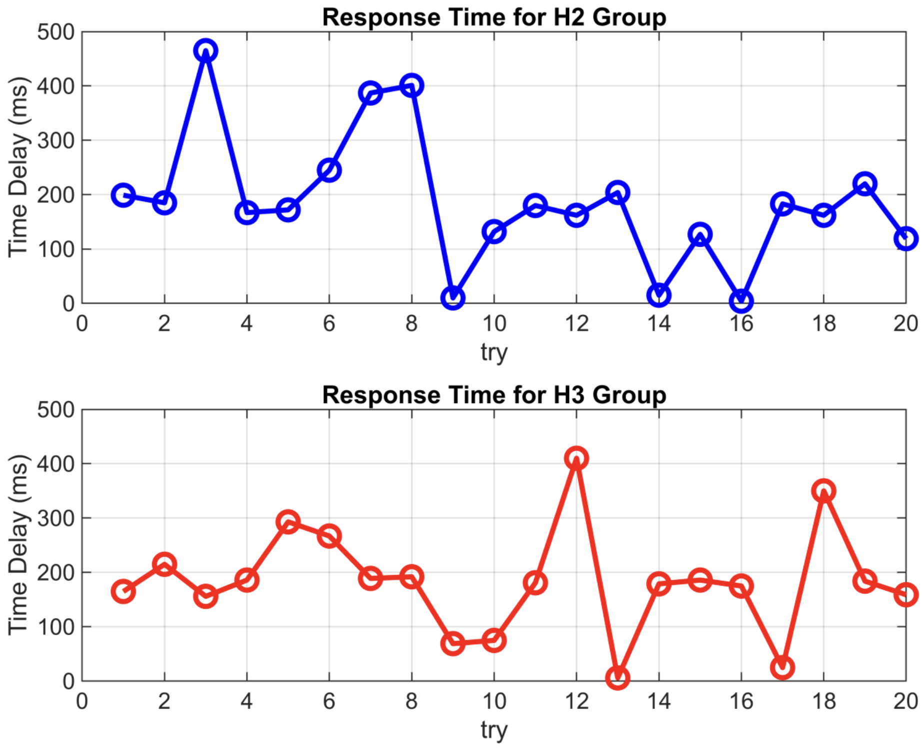
For H3 Group:
Mean response time: 183.10 ms
Standard deviation: 97.98 ms

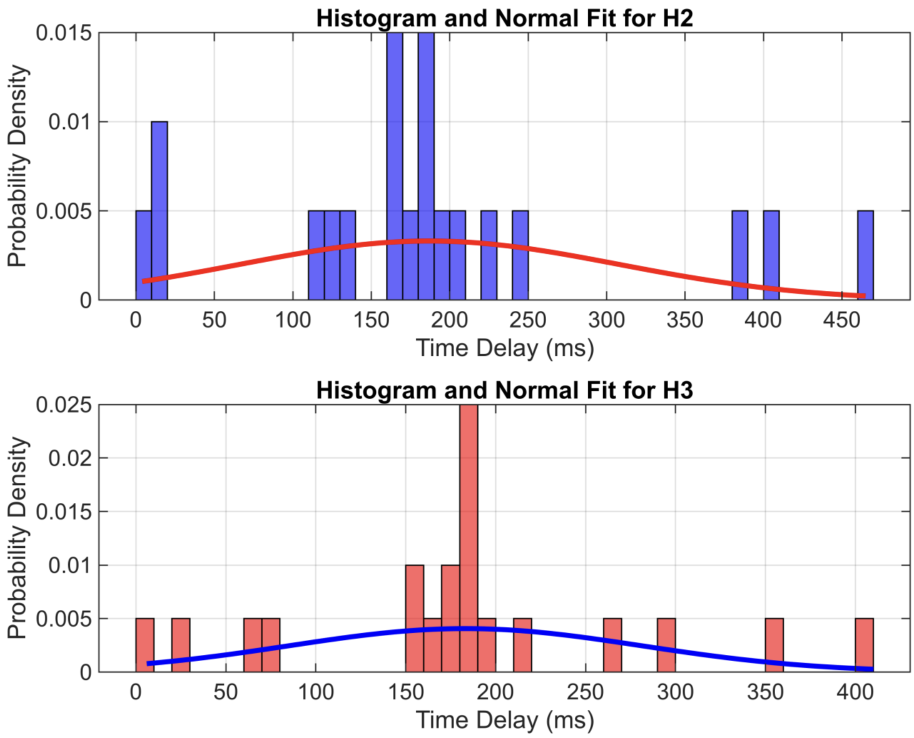
Understanding the Mean: The mean response time represents the *average* reaction time recorded in each experiment. Since the mean values for H2 (186.95 ms) and H3 (183.10 ms) are **very close**, we can say that, on average, both groups responded in nearly the same amount of time.

Understanding Standard Deviation: Standard deviation tells us how much the individual response times vary from the mean.

- The **H2 group** has a standard deviation of **120.43 ms**, meaning there is a **wider spread** in response times—some tries reacted much faster or slower.
- The **H3 group** has a standard deviation of **97.98 ms**, meaning the responses were **more consistent** and closer to the average.

In simpler terms, the H2 group had **more variation**, whereas the H3 group was **more stable** in their reaction times.


Response Time for H2 Group
Time Delay (ms)
try
Response Time for H3 Group
Time Delay (ms)
try


Histogram and Normal Fit for H2
Probability Density
Time Delay (ms)
Histogram and Normal Fit for H3
Probability Density
Time Delay (ms)

Question 3

Are the **statistical behaviors** of the data from the two experiments different?

Answer

The two experiments show **different statistical behaviors** but both obey from normal distributions with near mean but some different standard deviations.

How much do the reaction times vary?

The **H2 group** had a **higher standard deviation**, meaning that the response times varied significantly. Some tries reacted very quickly, while others took much longer. The **H3 group**, on the other hand, had a lower standard deviation, meaning that **most responses were clustered closer to the mean**. This suggests that the H3 group was more consistent in their reaction times.

Shape of the Data Distribution

Looking at the histograms:

- The **H2 group's histogram** is more **spread out**, with reaction times ranging from very low (4 ms) to very high (465 ms).
- The **H3 group's histogram** is more **concentrated**, meaning that most participants responded within a smaller time range.

Are there any extreme values (outliers)?

In the H2 group, there were **several extreme values**, meaning that some individuals took much longer or much shorter time to respond. In contrast, the H3 group had **fewer extreme values**, meaning the reaction times were more stable.

Although the **average response time** for both groups was nearly the same, the way people responded was different:

- **H2 group:** More variation in response times, more extreme values, and a less predictable pattern.
- **H3 group:** More consistent responses, with most participants reacting within a similar time-frame.

In summary, while both groups had similar average response times, **H2 was more erratic, while H3 followed a more structured and predictable pattern**.

Tables for Experiment 2

Table 1 - Density Measurement Data

M	1	2	3	4	5	6	7	8	10
T_1	0.200	0.420	0.610	0.830	1.025	1.300	1.600	1.950	2.275
T_2	0.130	0.270	0.390	0.530	0.625	0.850	1.050	1.250	1.450
$B = T_1 - T_2$	0.070	0.150	0.220	0.300	0.400	0.450	0.550	0.700	0.825

Table 3: Density Measurement using Archimedes' Principle

Table 2 - Reaction Time Measurement (First Subject)

Try	1	2	3	4	5	6	7	8	9	10
Time (ms)	199	185	465	167	172	245	387	401	10	132
Time (ms)	180	162	204	15	127	4	183	162	220	119

Table 4: Reaction Time Data for First Subject

Table 3 - Reaction Time Measurement (Second Subject)

Try	1	2	3	4	5	6	7	8	9	10
Time (ms)	165	215	156	182	293	267	189	192	69	75
Time (ms)	181	410	6	179	186	175	25	350	184	159

Table 5: Reaction Time Data for Second Subject