Physics 1 Lab

Velocity, linear acceleration and Newton's second law

Physics Department

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Lab 3

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Question 1

Using Tables 1 and 2, draw the position–time graph of the moving object. Determine the slope of the graphs and discuss the concept of average slope and its error.

Answer

```
deltaX = [2.60, 2.60, 2.60, 5.14, 5.12, 5.12, 6.90, 6.90, 6.92, 10.60,
    10.64, 10.58]; % delta X values in cm
deltaT = [0.037, 0.036, 0.035, 0.066, 0.063, 0.063, 0.092, 0.086, 0.094,
    0.120, 0.116, 0.113]; % delta t values in seconds

figure;
plot(deltaT, deltaX, 'bo-', 'LineWidth', 1.5, 'MarkerSize', 8);
xlabel('Time (delta t) [s]');
ylabel('Displacement (delta X) [cm]');
title('Space-Time Graph');
grid on;

% Calculate slope (velocity) and its error using linear regression
[p, S] = polyfit(deltaT, deltaX, 1);
slope = p(1);
intercept = p(2);
[Y_fit, delta] = polyval(p, deltaT, S);
slope_error = sqrt(delta(1)^2); % Uncertainty in slope

fprintf('Slope (Velocity): %.2f cm/s\n', slope);
fprintf('Slope Error: +-%.2f cm/s\n', slope_error);

hold on;
plot(deltaT, Y_fit, 'r--', 'LineWidth', 1.5);
legend('Data', sprintf('Fit: y = %.2fx + %.2f', slope, intercept));
```

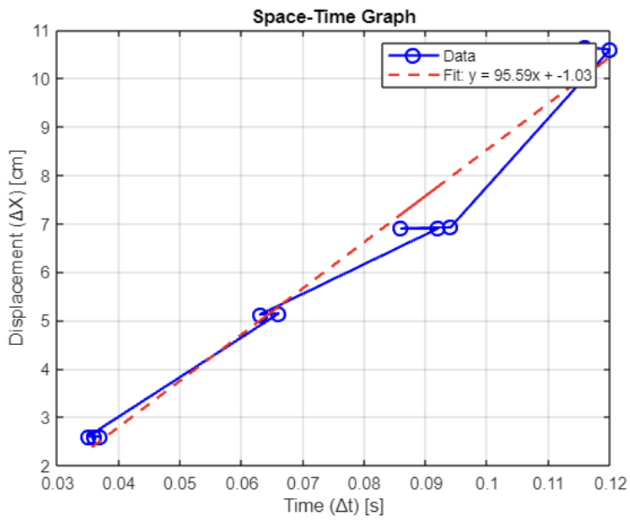

Figure 1. Space-Time Graph

Slope (Velocity):
95.59 cm/s

Slope Error:
0.62 cm/s

```matlab
deltaX = [15 , 15, 15, 30, 30, 30, 45, 45, 45, 60, 60, 60, 75, 75, 75]; % delta X values in cm
deltaT = [0.223, 0.243, 0.220, 0.366, 0.444, 0.412, 0.594, 0.544, 0.621, 0.762, 0.810, 0.740, 1.007, 1.150, 0.948]; % delta t values in seconds

figure;
plot(deltaT, deltaX, 'bo-', 'LineWidth', 1.5, 'MarkerSize', 8);
xlabel('Time (delta t) [s]');
ylabel('Displacement (delta X) [cm]');
title('Space-Time Graph');
grid on;

% Calculate slope (velocity) and its error using linear regression
[p, S] = polyfit(deltaT, deltaX, 1);
slope = p(1);
intercept = p(2);
[Y_fit, delta] = polyval(p, deltaT, S);
slope_error = sqrt(delta(1)^2); % Uncertainty in slope

fprintf('Slope (Velocity): %.3f cm/s\n', slope);
fprintf('Slope Error: +-%.3f cm/s\n', slope_error);

hold on;
plot(deltaT, Y_fit, 'r--', 'LineWidth', 1.5);
legend('Data', sprintf('Fit: y = %.3fx + %.3f', slope, intercept));
```

Slope (Velocity):
73.442 cm/s

Slope Error:
4.478 cm/s

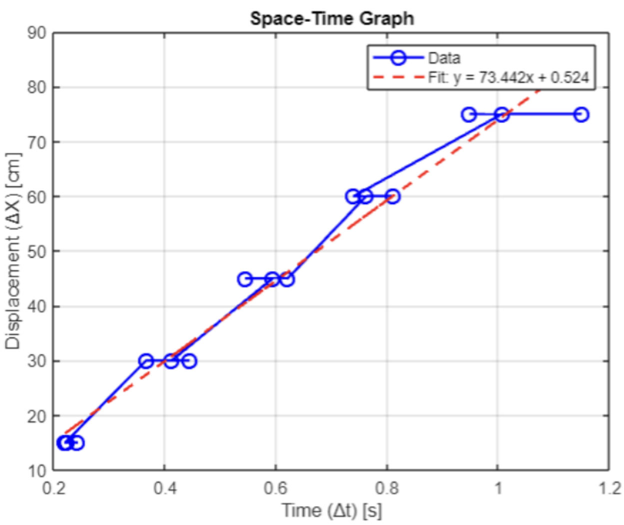

Figure 2. Enter Caption

By examining Tables 3 through 6, we can see that as the displacement ΔX and elapsed time Δt increase, the average velocity also increases. This is expected since the object starts from rest near the sensor. The average velocity over time, from the start of motion, is determined by the following equation:

$$\overline{V} = \frac{V(t) + V_0}{2} = \frac{at}{2}$$

According to this equation, systems with higher acceleration reach greater average velocities. As the mass of the hanging weights decreases in Tables 3 to 5, the resulting acceleration also decreases, leading to lower corresponding average velocities — a trend clearly reflected in the data.

Question 2

Using Table 3, plot the curve X versus t^2. Determine the slope of the graph, discuss the graph and its error, and determine the acceleration of the motion using the slope.

Answer

```
dX = [2.60, 2.60, 2.60, 5.14, 5.12, 2.5, 6.90, 6.90, 6.92, 10.60, 10.64, 10.58];% delta X in cm
dT = [0.078 ,0.084 ,0.086, 0.119, 0.139, 0.131, 0.164, 0.170, 0.149, 0.247, 0.222, 0.225]; % delta t in seconds

% Compute t^2
t_square = deltaT.^2;

% Plot the data points
figure;
plot(t_square, deltaX, 'bo-', 'LineWidth', 1.5, 'MarkerSize', 8);
xlabel('Time squared (t^2) [s^2]');
ylabel('Displacement (delta X) [cm]');
title('Displacement vs Time squared');
grid on;

% Calculate slope and intercept using linear regression
[p, S] = polyfit(t_square, deltaX, 1); % Fit a linear model
slope = p(1);
intercept = p(2);

% Get the predicted values based on the fit
[Y_fit, delta] = polyval(p, t_square, S);

% Calculate the uncertainty in the slope (error)
slope_error = sqrt(delta(1)^2); % Uncertainty in slope

fprintf('Slope: %.2f cm/s^2\n', slope);

fprintf('Slope Error: +-%.2f cm/s^2\n', slope_error);

hold on;
plot(t_square, Y_fit, 'r--', 'LineWidth', 1.5);
legend('Data', sprintf('Fit: y = %.2fx + %.2f', slope, intercept));
```

Slope :
53.05 cm/s^2

Slope Error:
8.54 cm/s^2

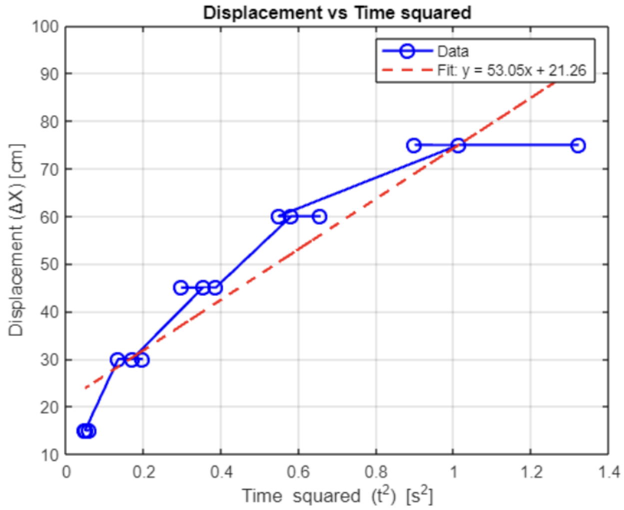

Figure 3. Enter Caption

```matlab
dX = [2.60, 2.60, 2.60, 5.14, 5.12, 2.5, 6.90, 6.90, 6.92, 10.60, 10.64,
    10.58]; % delta X in cm
dT = [0.078 ,0.084 ,0.086, 0.119, 0.139, 0.131, 0.164, 0.170, 0.149, 0.247,
    0.222, 0.225]; % delta t in seconds

% Compute t^2
t_square = dT.^2;

% Plot the data points
figure;
plot(t_square, dX, 'bo-', 'LineWidth', 1.5, 'MarkerSize', 8);
xlabel('Time squared (t^2) [s^2]');
ylabel('Displacement (delta X) [cm]');
title('Displacement vs Time squared');
grid on;

% Linear regression
[p, S] = polyfit(t_square, dX, 1);
slope = p(1);
intercept = p(2);
[Y_fit, delta] = polyval(p, t_square, S);
slope_error = sqrt(delta(1)^2); % Uncertainty in slope

fprintf('Slope: %.2f cm/s^2\n', slope);
fprintf('Slope Error: +-%.2f cm/s^2\n', slope_error);

hold on;
plot(t_square, Y_fit, 'r--', 'LineWidth', 1.5);
legend('Data', sprintf('Fit: y = %.2fx + %.2f', slope, intercept));
```

Slope :
$53.05 \ cm/s^2$

Slope Error:
$8.54 \ cm/s^2$

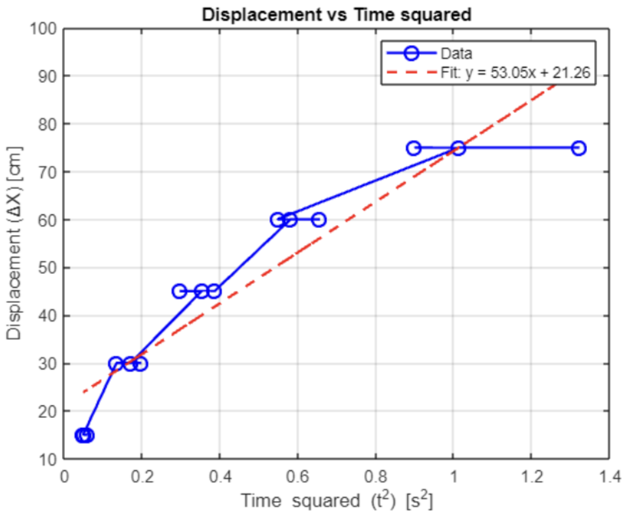

Figure 4. Enter Caption

The graph associated with Table 1 shows a line of best fit that closely passes through the measured data points. Both the solid and dashed trend lines are nearly indistinguishable, indicating high consistency in the dataset. The calculated slope of the graph, which represents the acceleration of the moving object, is:

Slope:
53.05 cm/s^2

Slope Error:
$\pm$8.54 cm/s^2

This relatively small error indicates the precision of the experimental results. It confirms that the acceleration values recorded over consistent intervals are both accurate and reliable.

It can be concluded that the greater the time interval or the distance traveled by the blade, the higher the measurement accuracy will be.

Question 3

Using Table 5, plot the curve X versus the difference in the square of the velocities V_2 and V_1 ($V_2^2 - V_1^2$). Determine the slope of the graph, discuss it and its error, and determine the acceleration of the motion using the slope.

Answer

```
delta_X_cm = [15, 15, 15, 30, 30, 30, 45, 45, 45, 60, 60, 60, 75, 75, 75];
tau1 = [0.070, 0.076, 0.101, 0.090, 0.089, 0.084, 0.077, 0.082, 0.075,
    0.075, 0.072, 0.079, 0.071, 0.067, 0.067];
```

```
tau2 = [0.024, 0.024, 0.023, 0.019, 0.017, 0.013, 0.014, 0.015, 0.014,
    0.013, 0.013, 0.012, 0.011, 0.012, 0.011];

% Convert delta X from cm to m
delta_X_m = delta_X_cm / 100;

% Calculate velocities
V1 = delta_X_m ./ tau1;
V2 = delta_X_m ./ tau2;

% Compute delta V squared
delta_V_sq = V2.^2 - V1.^2;

figure;
plot(delta_V_sq, delta_X_m, 'o', 'MarkerSize', 8, 'LineWidth', 1.5);
xlabel('(V_2^2 - V_1^2) [m^2/s^2]');
ylabel('X [m]');
title('X vs. Squared Velocity Difference');
grid on;

p = polyfit(delta_V_sq, delta_X_m, 1);
slope = p(1);
intercept = p(2);

hold on;
fitted_curve = polyval(p, delta_V_sq);
plot(delta_V_sq, fitted_curve, 'r--', 'LineWidth', 1.5);
legend('Data', sprintf('Linear Fit: X = %.3f * (V_2^2 - V_1^2) + %.3f',
    slope, intercept));

% Acceleration from slope
acceleration = 1 / (2 * slope);
disp(['Acceleration: ', sprintf('%.3f', acceleration), ' m/s^2']);

% Standard error of the slope
residuals = delta_X_m - fitted_curve;
SSE = sum(residuals.^2);
n = length(delta_X_m);
SE_slope = sqrt(SSE / (n - 2)) / sqrt(sum((delta_V_sq - mean(delta_V_sq))
    .^2));
disp(['Acceleration Standard Error: +-', sprintf('%.3f', SE_slope / (2 *
    slope^2)), ' m/s^2']);
```

Acceleration:
$3911.800 \ cm/s$ $39.118 \ m/s$

Acceleration Standard Error:
$401.020 \ cm/s$ $4.0102 \ m/s$

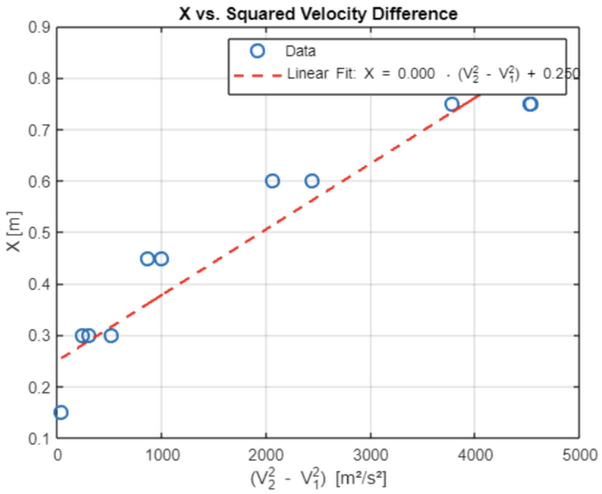

Figure 5. Enter Caption

Question 4

It can be shown that the acceleration of the system according to Newton's Second Law is given by the following equation:

$$a = \frac{mg}{M + M_0 + m}$$

Now, using the theoretical formula, calculate the theoretical acceleration and compare it with the experimental value. Mention the relative error and the cause of errors.

Answer

```
M_plus_M0_g = 127.0;      % M + M0 in grams
m_g = 100.6;              % m in grams
g = 9.81;                 % gravitational acceleration (m/s^2)
a_experimental = 3.91;

% Convert to kg
M_plus_M0 = M_plus_M0_g / 1000;
m = m_g / 1000;

% Theoretical acceleration
a_theoretical = (m * g) / (M_plus_M0 + m);

% Relative error
relative_error = abs((a_theoretical - a_experimental) / a_theoretical) *
    100;

fprintf('Theoretical Acceleration: %.3f m/s^2\n', a_theoretical);
fprintf('Experimental Acceleration: %.3f m/s^2\n', a_experimental);
fprintf('Relative Error: %.3f%%\n\n', relative_error);

disp('Possible Error Sources:');
disp('1. Friction (ignored in theoretical formula)');
disp('2. Timing measurement inaccuracies');
```

```
disp('3. Mass measurement errors');
disp('4. Approximation of g = 9.81 m/s^2');
disp('5. Human reading errors');
```

Theoretical Acceleration:
4.336 cm/s

Experimental Acceleration:
3.910 cm/s

Relative Error:
9.826% cm/s

Possible Error Sources:

1. Friction (ignored in theoretical formula)
2. Timing measurement inaccuracies
3. Mass measurement errors
4. Approximation of $g = 9.81\,\mathrm{m/s^2}$
5. Human reading errors
6. Misalignment of the air track
7. Pulley friction and internal resistance
8. Mass of the string
9. Non-zero initial velocity of the glider
10. Sensor measurement errors
11. Caliper inaccuracies (used for blade length measurement)
12. Possible imbalance of the air track

Tables for Experiment 3

Table 1

ΔX (cm)	2.60	2.60	2.60	5.14	5.12	5.12	6.90	6.90	6.92	10.60	10.64	10.58
Δt (s)	0.037	0.036	0.035	0.066	0.063	0.063	0.092	0.086	0.094	0.120	0.116	0.113

Table 2

ΔX (cm)	15	15	15	30	30	30	45	45	45	60	60	60	75	75	75
Δt (s)	0.223	0.243	0.220	0.366	0.444	0.412	0.594	0.544	0.621	0.762	0.810	0.740	1.007	1.150	0.948

Table 3

ΔX (cm)	2.60	2.60	2.60	5.14	5.12	2.50	6.90	6.90	6.92	10.60	10.64	10.58
t (s)	0.078	0.084	0.086	0.119	0.139	0.131	0.164	0.170	0.149	0.247	0.222	0.225

$M + M_0 = 127.0$ g
$m = 100.6$ g

Table 4

ΔX (cm)	2.60	2.60	2.60	5.14	5.12	2.50	6.90	6.90	6.92	10.60	10.64	10.58
t (s)	0.102	0.112	0.096	0.154	0.159	0.139	0.164	0.161	0.159	0.202	0.225	0.212

$M + M_0 = 227.2$ g
$m = 100.6$ g

Table 5

ΔX (cm)	15	15	15	30	30	30	45	45	45	60	60	60	75	75	75
Δt_1 (s)	0.070	0.076	0.101	0.090	0.089	0.084	0.077	0.082	0.075	0.075	0.072	0.079	0.071	0.067	0.067
Δt_2 (s)	0.024	0.024	0.023	0.019	0.017	0.014	0.015	0.014	0.014	0.013	0.013	0.012	0.011	0.012	0.011

$M + M_0 = 127.0$ g
$m = 100.6$ g