Physics 1 Lab

Friction

Physics Department

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Lab 4

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Friction

Data Analysis Table 1:

(a)

Draw the force-extension curve of the string according to the added weights on a piece of millimeter paper using a ruler and straightedge. Now draw the linear equation or determine the coefficient of friction in each case from the slope of the curve. Draw both curves on a single piece of millimeter paper but use different colors for the different weights.

```
weights = [100, 300, 500, 700, 900];
m = 29.3; % Cube mass (g)
m =m/1000;
g = 9.78;


friction_coated = [150 , 220 , 290 , 375 , 430 ]*g*0.001 % Friction force for coated surface (Newtons)

friction_wood = [56,80,120,134,146]*g*0.001 % Friction force for wooden surface (Newtons)

% Calculate normal force (N = (m + weight) * g)
weight_kg = weights / 1000; % Convert grams to kg
N_coated = (m + weight_kg) * g; % Normal force for coated surface
N_wood = (m + weight_kg) * g; % Normal force for wooden surface

figure;
hold on;

plot(weights, friction_coated, 'ro', 'MarkerSize', 8, 'LineWidth', 1.5);
p1 = polyfit(weights, friction_coated, 1);
fit_coated = polyval(p1, weights);
plot(weights, fit_coated, 'r-', 'LineWidth', 1.5);

plot(weights, friction_wood, 'bo', 'MarkerSize', 8, 'LineWidth', 1.5);
p2 = polyfit(weights, friction_wood, 1);
fit_wood = polyval(p2, weights);
plot(weights, fit_wood, 'b-', 'LineWidth', 1.5);

grid on;
xlabel('weights(gr)');
ylabel('Friction Force (N)');
title('Tension Force vs. weights(gr)');
legend('Coated Surface', 'Coated Regression', 'Wooden Surface', 'Wooden Regression');

% Calculate friction coefficient (mu = slope *1000/ g)
mu_coated = p1(1) / g*1000;
mu_wood = p2(1) / g*1000;

fprintf('Coated surface friction coefficient: mu = %.3f\n', mu_coated);

fprintf('Wooden surface friction coefficient: mu = %.3f\n', mu_wood);
```

Friction Forces for Coated Surface (N):

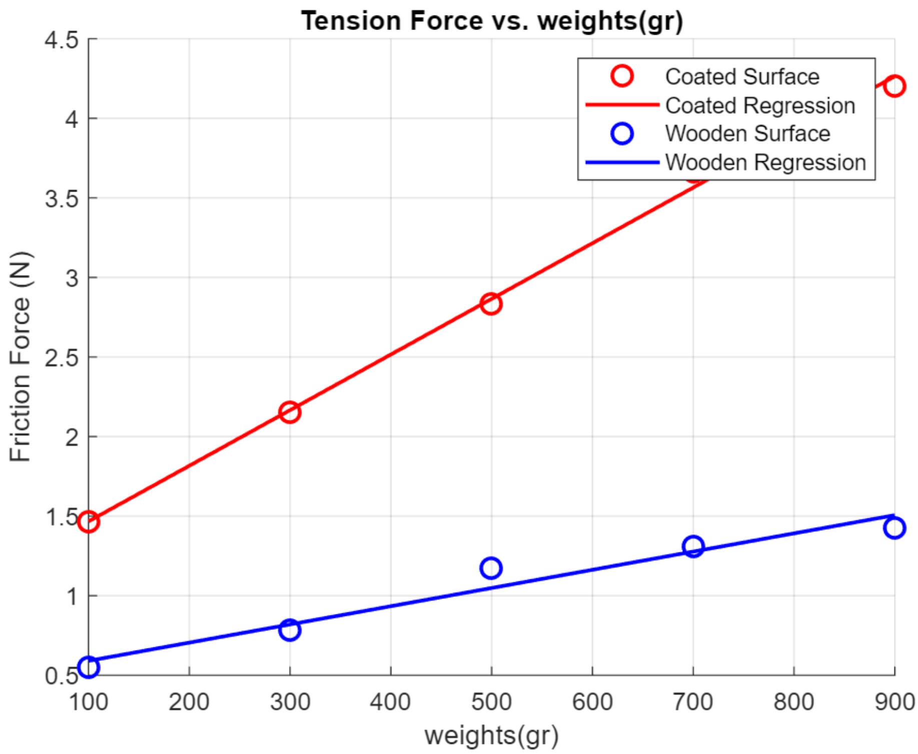
$$\text{friction\_coated} = \begin{bmatrix}1.4670 & 2.1516 & 2.8362 & 3.6675 & 4.2054\end{bmatrix}$$

Friction Forces for Wooden Surface (N):

$$\text{friction\_wood} = \begin{bmatrix}0.5477 & 0.7824 & 1.1736 & 1.3105 & 1.4279\end{bmatrix}$$

Calculated Friction Coefficients:

$$\mu_{\text{coated}} = 0.357 \qquad \mu_{\text{wood}} = 0.117$$



(b)

By extending one of the curves and intersecting it with the axes, find mc_1 and mc_2. Do not write a mathematical relationship, because due to experimental errors, this is likely not a correct answer. Therefore, for better approximation, consider the average of mc_1 and mc_2.

```
% Input data (replace with actual measurements)
weights = [100, 300, 500, 700, 900];
m = 29.3; % Cube mass (g)
m =m/1000;
g = 9.78;


friction_coated = [150 , 220 , 290 , 375 , 430 ]*g*0.001; % Friction force
    for coated surface (Newtons)
```

```
friction_wood = [56,80,120,134,146]*g*0.001; % Friction force for wooden surface (Newtons)

% Calculate normal force (N = (m + added mass) * g)
weight_kg = weights / 1000; % Convert grams to kg
N_coated = (m + weight_kg) * g; % Normal force for coated surface
N_wood = (m + weight_kg) * g; % Normal force for wooden surface

% Linear regression for both surfaces
p_coated = polyfit(N_coated, friction_coated, 1); % Format: [slope, intercept]
p_wood = polyfit(N_wood, friction_wood, 1);

% Calculate mc1 and mc2 from intercept and slope
mc1 = (p_coated(2) / p_coated(1)) / g; % Mass from coated surface
mc2 = (p_wood(2) / p_wood(1)) / g; % Mass from wooden surface

% Average the masses
mc = (mc1 + mc2) / 2;

% Display results
fprintf('mc1 (Coated Surface): %.3f kg\n', mc1/10);
fprintf('mc2 (Wooden Surface): %.3f kg\n', mc2/10);
fprintf('Approximated Cube Mass (mc): %.3f kg\n', mc/10);
```

Estimated Mass from Coated Surface:

$$mc_1 = 0.029 \text{ kg}$$

Estimated Mass from Wooden Surface:

$$mc_2 = 0.039 \text{ kg}$$

Average Approximated Mass:

$$mc = 0.034 \text{ kg}$$

(c)

Calculate the mass obtained through the curvature method and the measured mass using a scale and compare them. Determine the measurement error (relative error) between the two quantities.

```
m_balance = 29.3; % Cube mass measured by balance (grams)

% Calculate relative error
relative_error = abs((100*mc - m_balance)/m_balance) * 100;

% Display results
fprintf('Cube mass from coated surface (mc1): %.1f g\n', 100*mc1);
fprintf('Cube mass from wooden surface (mc2): %.1f g\n', 100*mc2);
fprintf('Average calculated mass (mc): %.1f g\n', 100*mc);
fprintf('Balance-measured mass: %.1f g\n', m_balance);
fprintf('Relative error: %.1f%%\n', relative_error);
```

Cube Mass from Coated Surface:

$$mc_1 = 29.0 \text{ g}$$

Cube Mass from Wooden Surface:

$$mc_2 = 38.7 \text{ g}$$

Average Calculated Mass:

$$mc = 33.9 \text{ g}$$

Mass Measured by Balance:

$$m_{\text{balance}} = 29.3 \text{ g}$$

Relative Error:

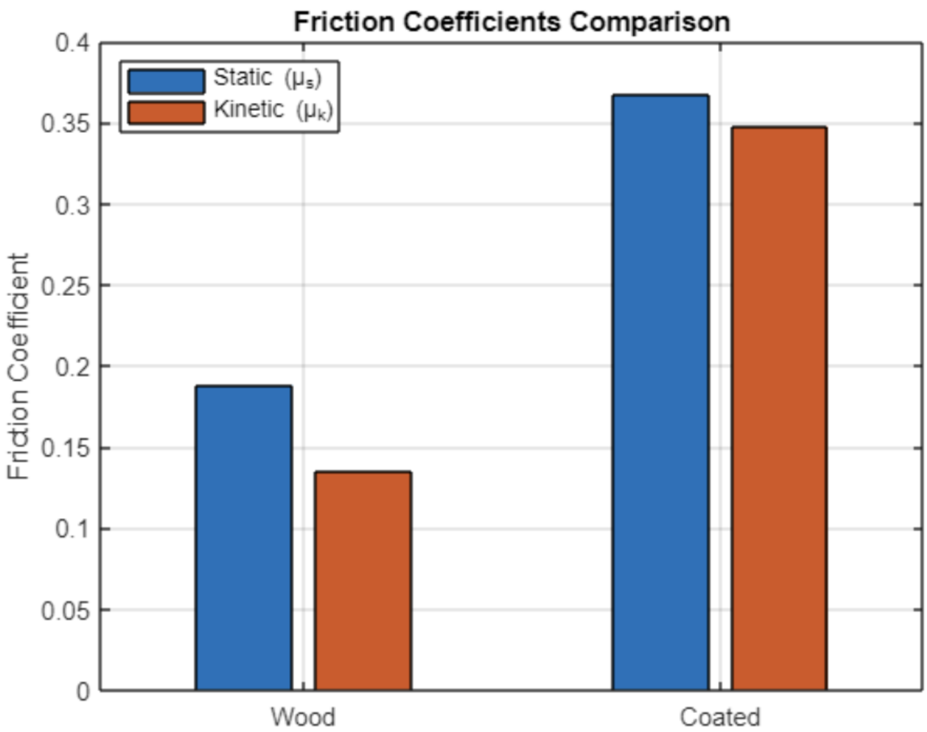
$$\text{Relative Error} = 15.6\%$$

Data Analysis Table 2:

Determine the average values θ_k and θ_s at each stage using Equations (4) and (5), and calculate μ_{k1}, μ_{k2}, and μ_{k3}. Using the results, explain what conclusions can be drawn regarding the effect of surface material.

```
% Data Input
% Static Angles (theta_s)
theta_s_wood = [10, 11, 11];           % Wood/rough surface static angles
theta_s_coated = [20, 20.5,20];      % Coated surface static angles

% Kinetic Angles (theta_k)
theta_k_wood = [7.5, 8, 7.5];        % Wood/rough surface kinetic angles
theta_k_coated =[19,19.5,19]  ;      % Coated surface kinetic angles

% Calculate averages
avg_theta_s_wood = mean(theta_s_wood);
avg_theta_s_coated = mean(theta_s_coated);
avg_theta_k_wood = mean(theta_k_wood);
avg_theta_k_coated = mean(theta_k_coated);

% Convert to radians
theta_s_wood_rad = deg2rad(avg_theta_s_wood);
theta_s_coated_rad = deg2rad(avg_theta_s_coated);
theta_k_wood_rad = deg2rad(avg_theta_k_wood);
theta_k_coated_rad = deg2rad(avg_theta_k_coated);

% Calculate friction coefficients
mu_s_wood = tan(theta_s_wood_rad);
mu_k_wood = tan(theta_k_wood_rad);
mu_s_coated = tan(theta_s_coated_rad);
mu_k_coated = tan(theta_k_coated_rad);

% Display results
fprintf('==== Wood/Rough Surface ====\n');
fprintf('Average theta_s: %.1f\n', avg_theta_s_wood);
fprintf('Average theta_k: %.1f\n', avg_theta_k_wood);
fprintf('mu_s = %.3f\n', mu_s_wood);
```

```
fprintf('mu_k = %.3f\n', mu_k_wood);
fprintf('mu_s - mu_k = %.3f\n\n', mu_s_wood - mu_k_wood);

fprintf('==== Coated Surface ====\n');
fprintf('Average theta_s: %.1f\n', avg_theta_s_coated);
fprintf('Average theta_k: %.1f\n', avg_theta_k_coated);
fprintf('mu_s = %.3f\n', mu_s_coated);
fprintf('mu_k = %.3f\n', mu_k_coated);
fprintf('mu_s - mu_k = %.3f\n\n', mu_s_coated - mu_k_coated);

figure;
surfaces = {'Wood', 'Coated'};
mu_s = [mu_s_wood, mu_s_coated];
mu_k = [mu_k_wood, mu_k_coated];

bar([mu_s; mu_k]');
set(gca, 'XTickLabel', surfaces);
ylabel('Friction Coefficient');
legend('Static (mu_s)', 'Kinetic (mu_k)', 'Location', 'northwest');
title('Friction Coefficients Comparison');
grid on;
```



Wood / Rough Surface:

- Average θ_s: 10.7°
- Average θ_k: 7.7°
- Static friction coefficient: $\mu_s = 0.188$
- Kinetic friction coefficient: $\mu_k = 0.135$
- Difference: $\mu_s - \mu_k = 0.054$

Coated Surface:

- Average θ_s: 20.2°
- Average θ_k: 19.2°
- Static friction coefficient: $\mu_s = 0.367$
- Kinetic friction coefficient: $\mu_k = 0.348$
- Difference: $\mu_s - \mu_k = 0.020$

As can be seen, contrary to expectations and to the requirement in part 1(a), the friction coefficients for the coated surface were found to be higher than those for the uncoated wooden surface, which is consistent with the explanation provided in part 1(a).

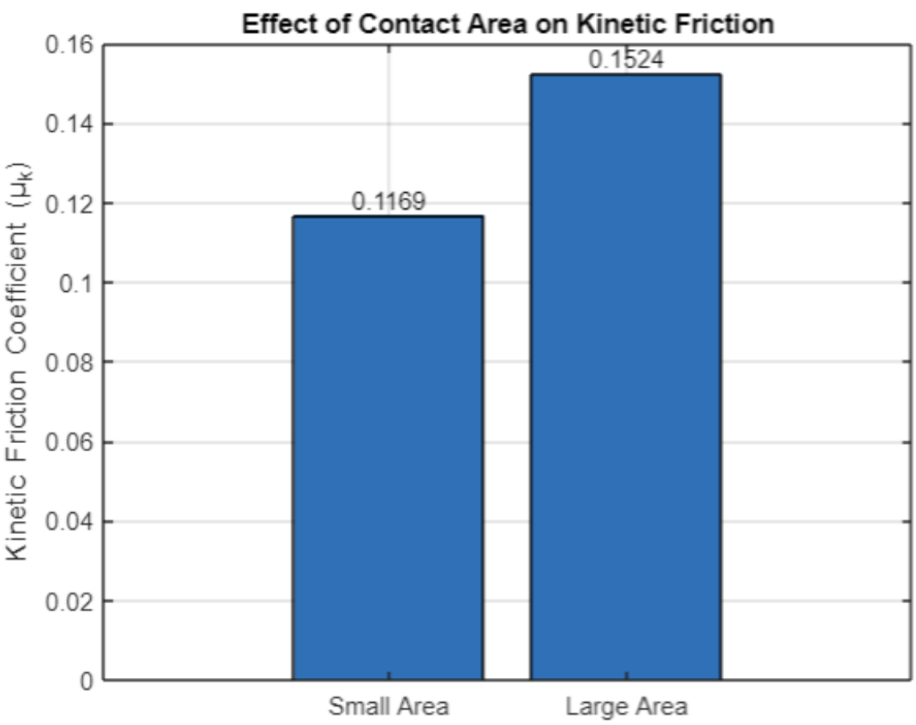
Data Analysis Table 3:

Determine the average values θ_k and θ_s at each stage using Equations (4) and (5), and calculate μ_{k1}, μ_{k2}, and μ_{k3}. Compare the results with those of Levels (1) and (2) and explain why the expected outcomes may differ. If there is any difference, identify the reason.

Compare the coefficient of static friction and kinetic friction using the data from Table 4 and the method of operation on the surface. Explain how the force diagrams change before and after reversing the direction of motion.

```
% Surface 2 (Smaller contact area)
theta_k_surface2 = [6.5, 6.5, 7]; % Kinetic angles in degrees

% Surface 3 (Larger contact area)
theta_k_surface3 = [9, 8.5, 8.5]; % Kinetic angles in degrees

% Calculate mean angles
mean_theta2 = mean(theta_k_surface2);
mean_theta3 = mean(theta_k_surface3);

% Convert angles to radians
theta2_rad = deg2rad(mean_theta2);
theta3_rad = deg2rad(mean_theta3);

% Calculate kinetic friction coefficients
mu_k_surface2 = tan(theta2_rad);
mu_k_surface3 = tan(theta3_rad);

% Calculate difference
mu_diff = abs(mu_k_surface3 - mu_k_surface2);

fprintf('==== Surface 2 (Small Area) ====\n');
fprintf('Mean theta_k: %.2f\n', mean_theta2);
fprintf('mu_k = tan(%.2f) = %.4f\n\n', mean_theta2, mu_k_surface2);

fprintf('==== Surface 3 (Large Area) ====\n');
fprintf('Mean theta_k: %.2f\n', mean_theta3);
fprintf('mu_k = tan(%.2f) = %.4f\n\n', mean_theta3, mu_k_surface3);

fprintf('Difference: |mu_k3 - mu_k2| = %.4f\n', mu_diff);
```

```
figure;
surfaces = {'Small Area', 'Large Area'};
mu_values = [mu_k_surface2, mu_k_surface3];

bar(mu_values);
set(gca, 'XTickLabel', surfaces);
ylabel('Kinetic Friction Coefficient (mu_k)');
title('Effect of Contact Area on Kinetic Friction');
grid on;

% Add value labels
text(1:length(mu_values), mu_values, num2str(mu_values','%.4f'),...
    'HorizontalAlignment','center',...
    'VerticalAlignment','bottom')
```



Surface 2 (Small Area):

- Mean $\theta_k = 6.67^\circ$
- $\mu_k = \tan(6.67^\circ) = 0.1169$

Surface 3 (Large Area):

- Mean $\theta_k = 8.67^\circ$
- $\mu_k = \tan(8.67^\circ) = 0.1524$

Difference between Friction Coefficients:

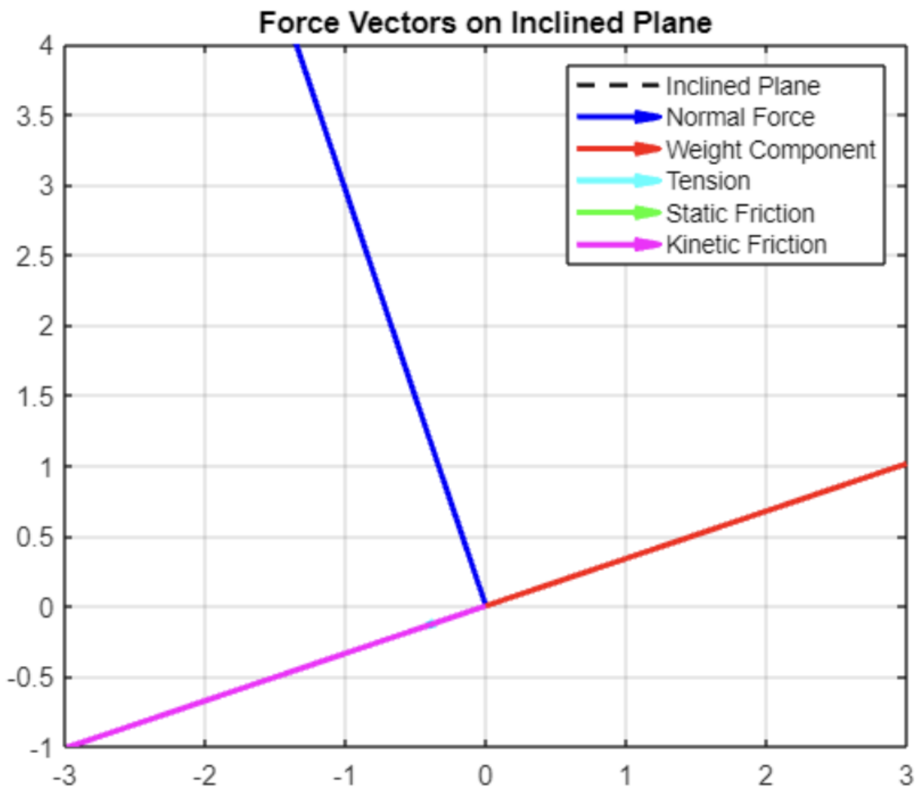
$$|\mu_{k3} - \mu_{k2}| = 0.0355$$

It was expected that the values would be equal, since the coefficient and force of friction do not depend on the surface area. However, the values obtained in this section show a relatively large difference, which seems to be due to differences in the material of the surfaces of different faces of the block. As we mentioned at the beginning of the experiment, we performed all tests on a specific area of the wooden surface because the friction varies across different parts of the wood. The same applies to the block as well; for this reason, we used a fixed and specific face of the block in all experiments.

Table 4

```
theta_s = [19,19,19.5]; % Static friction angles (degrees)
theta_k = [18 , 18.5 , 18]; % Kinetic friction angles (degrees)
m_weight_static = [52 ,52 ,52]/1000; % Hanging mass for static friction (kg)
m_weight_kinetic = [50 ,50 ,50]/1000; % Hanging mass for kinetic friction (
    kg)

% Calculate average masses
m_static = mean(m_weight_static);
m_kinetic = mean(m_weight_kinetic);

% Compute friction coefficients
mu_s = tan(deg2rad(theta_s)); % Static coefficients
mu_k = tan(deg2rad(theta_k)); % Kinetic coefficients
mu_s_avg = mean(mu_s);
mu_k_avg = mean(mu_k);

% Display results
fprintf('Average static friction coefficient: %.3f\n', mu_s_avg);
fprintf('Average kinetic friction coefficient: %.3f\n\n', mu_k_avg);


m_slope = 10; % Mass on inclined plane (kg)
g = 9.78;      % Gravitational acceleration (m/s^2)
theta = mean((theta_s+theta_k)/2);     % Incline angle (degrees)
theta_rad = deg2rad(theta);

% Static friction forces
N_static = m_slope * g * cos(theta_rad); % Normal force
F_gravity_static = m_slope * g * sin(theta_rad); % Parallel weight component
T_static = m_static * g; % Hanging mass tension
F_net_static = F_gravity_static - T_static; % Net force
F_friction_static = mu_s_avg * N_static; % Static friction

% Kinetic friction forces
N_kinetic = m_slope * g * cos(theta_rad); % Normal force
F_gravity_kinetic = m_slope * g * sin(theta_rad); % Parallel weight
    component
T_kinetic = m_kinetic * g; % Hanging mass tension
F_net_kinetic = F_gravity_kinetic - T_kinetic; % Net force
F_friction_kinetic = mu_k_avg * N_kinetic; % Kinetic friction

a = (F_net_kinetic - F_friction_kinetic) / m_slope;

fprintf('=== Static Forces ===\n');
fprintf('Normal force: %.2f N\n', N_static);
fprintf('Parallel weight component: %.2f N\n', F_gravity_static);
fprintf('Hanging mass tension: %.2f N\n', T_static);
fprintf('Maximum static friction: %.2f N\n', F_friction_static);
fprintf('Motion status: %s\n\n', ifelse(F_net_static > F_friction_static, '
    Motion starts', 'No motion'));

fprintf('=== Kinetic Forces ===\n');
fprintf('Normal force: %.2f N\n', N_kinetic);
fprintf('Parallel weight component: %.2f N\n', F_gravity_kinetic);
fprintf('Hanging mass tension: %.2f N\n', T_kinetic);
```

```
fprintf('Kinetic friction: %.2f N\n', F_friction_kinetic);
fprintf('Object acceleration: %.2f m/s^2\n\n', a);

figure;
R = [cos(theta_rad), -sin(theta_rad); sin(theta_rad), cos(theta_rad)]; %
    Rotation matrix
origin_rot = R * [0; 0]; % Rotated origin

x_surface = [-5, 5];
y_surface = tan(theta_rad) * x_surface;
plot(x_surface, y_surface, 'k--', 'LineWidth', 1.5);
hold on; axis equal; grid on;
xlim([-3, 3]); ylim([-1, 4]);
title('Force Vectors on Inclined Plane');

% Define forces
forces = {
    {'Normal Force', [0; N_static], 'b'},...
    {'Weight Component', [F_gravity_static; 0], 'r'},...
    {'Tension', [-T_static; 0], 'c'},...
    {'Static Friction', [-F_friction_static; 0], 'g'},...
    {'Kinetic Friction', [-F_friction_kinetic; 0], 'm'}...
};


for i = 1:length(forces)
    vec_rot = R * forces{i}{2};
    quiver(origin_rot(1), origin_rot(2), vec_rot(1), vec_rot(2),...
           'Color', forces{i}{3}, 'LineWidth', 2, 'MaxHeadSize', 0.5);
end

legend_labels = {'Inclined Plane', forces{1}{1}, forces{2}{1}, forces{3}{1},
    forces{4}{1}, forces{5}{1}};
legend(legend_labels);

function output = ifelse(condition, true_val, false_val)
    if condition
        output = true_val;
    else
        output = false_val;
    end
end
```



Friction Coefficients (Average):

$$\mu_s = 0.348 \qquad \mu_k = 0.328$$

Static Forces:

- Normal force: 92.66 N
- Parallel weight component: 31.30 N
- Hanging mass tension: 0.51 N
- Maximum static friction: 32.21 N
- **Motion status:** No motion

Kinetic Forces:

- Normal force: 92.66 N
- Parallel weight component: 31.30 N
- Hanging mass tension: 0.49 N
- Kinetic friction: 30.40 N
- Object acceleration: 0.04 m/s^2

Questions

1. Is the static friction force constant?
2. Why is it recommended to tap the surface lightly several times during the experiments to determine the kinetic friction coefficient, but not to do so when measuring the static friction coefficient?

Question 1

No, the static friction force is not constant. It is a variable force that adjusts itself in response to the applied force up to a certain limit. When an object is at rest, static friction opposes any force attempting to move it, increasing proportionally until it reaches a maximum value known as the maximum static friction ($F_{s,\max} = \mu_s N$). Only at this threshold does the object start to move. Therefore, while kinetic friction tends to be constant for a given surface and object, static friction can range from zero up to its maximum value depending on the magnitude of the applied force.

Question 2

When measuring the kinetic friction coefficient, it is important to ensure that the object is in uniform motion. Sometimes, due to small inconsistencies or sticking effects at the start of motion, the object may hesitate or experience non-uniform movement. Tapping the surface lightly helps to overcome these inconsistencies and ensures that the object slides smoothly, which leads to a more accurate measurement of kinetic friction.

On the other hand, when measuring the static friction coefficient, the goal is to determine the exact point at which the object just begins to move. If the surface is tapped, even lightly, it may prematurely disturb the object and cause it to move before the actual static friction limit is reached, leading to inaccurate or underestimated values. Thus, to measure the true maximum static friction, the surface should not be disturbed or tapped.