Mechanics Lab (Civil Engineers)

Name (please print): ____________________________

Date of lab: ____________________________________

Experiments

In the session you will be divided into groups and perform four separate experiments:

(1) air-track collisions;

(2) static and kinetic friction;

(3) flywheel experiment;

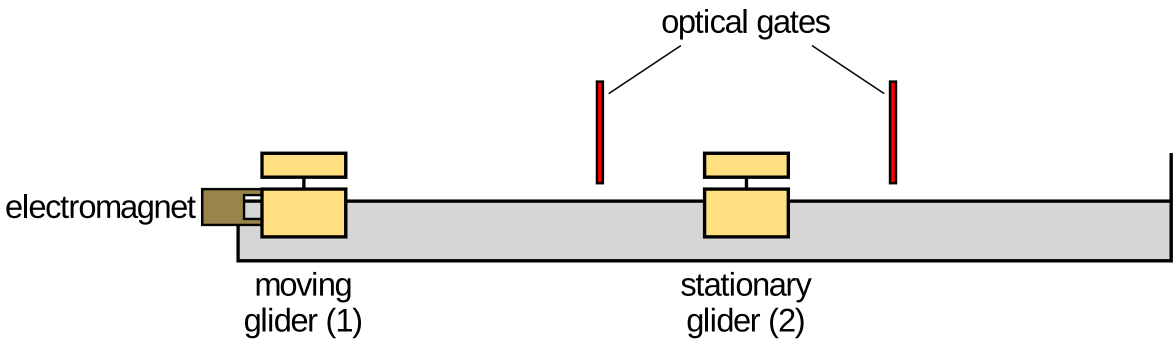
(4) mass-spring oscillations.

Write-Up and Submission

- Experimental data should be recorded and analysed during the laboratory session.
- Results and analysis should only be submitted on this worksheet.
- Submission is at the end of the lab and it is your responsibility to ensure that your worksheet is handed in.
- Work will be returned in class when everybody's report has been marked.
- This report constitutes 10% of the total marks for the Mechanics unit.

1. Air Track Collisions

The air track provides a nearly frictionless environment for experiments on objects moving in a straight line. You will use two "gliders", one initially stationary near the middle of the track and one set in motion by elastic propulsion. There is also a measuring system, which uses time-of-transit measurements with optical gates to determine the speed of the gliders.



Method

The optical gates should be either side of the starting point of the stationary glider. The other glider is held within a stretched loop of elastic by an electromagnet. When the electromagnet is switched off, its glider is propelled forward by the elastic. The glider's pre-collision velocity can be determined as it passes the first optical gate. After the collision, the final velocities of the two gliders can be determined as they pass one or other of the optical gates. You may need to adjust the position of the gates so that only one glider is passing a gate at a time, and you may need to catch one of the gliders.

The mass of each glider should be measured accurately with an electronic scale. Additional masses can be added to one or both of the gliders. Do the experiment with three combinations of masses. Write m_1 and m_2 for the masses of the two gliders, u_1 and u_2 for the initial velocity of each glider, and v_1 and v_2 for the signed velocities (negative if in the opposite direction to the initial motion).

Mass of moving glider (1)		kg
Mass of stationary glider (2)		kg

Results Tables

Record your measurements in the following table.

m_1 (kg)	m_2 (kg)	u_1 (m s^{-1})	u_2 (m s^{-1})	v_1 (m s^{-1})	v_2 (m s^{-1})
			0		
			0		
			0		

Analyse your results in the following table.

Initial momentum (kg m s^{-1})	Final momentum (kg m s^{-1})	Speed of approach (m s^{-1})	Speed of separation (m s^{-1})	Coefficient of restitution, e

Questions

1. For each experiment, calculate the total momentum before ($m_1u_1 + m_2u_2$) and the total momentum after ($m_1v_1 + m_2v_2$). What result do you anticipate obtaining?

2. For each experiment, calculate speed of approach, speed of separation and thus the coefficient of restitution, inserting values in the table.

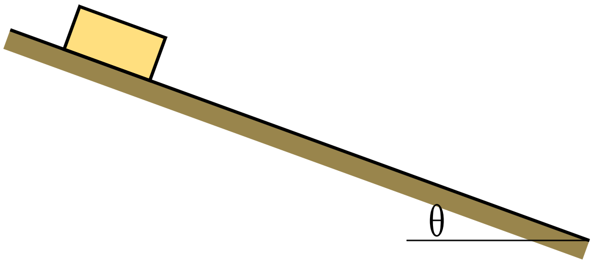
$$e = \frac{\text{speed of separation}}{\text{speed of approach}} = \frac{v_2 - v_1}{u_1 - u_2}$$

What would a value $e = 1$ mean?

What would a value $e = 0$ mean?

Suggest sources of error in the experiment.

2. Static and Kinetic Friction



A mass m is placed at rest on an inclined slope at angle θ to the horizontal. As the angle is slowly increased the component of weight down the slope increases and eventually exceeds the static friction between the mass and the slope. This can be used to determine the coefficient of static friction (μ_s) from

$$\mu_s = \tan \theta_s$$

where θ_s is the angle of incipient motion.

If the mass is given an initial push to start it moving, it will be subject to kinetic friction. Friction and downslope weight component will be in equilibrium (and hence the mass will just keep moving) when

$$\mu_k = \tan \theta_k$$

For 3 different objects:

- measure the angle θ_s at which the stationary mass just *starts* to slide, and hence deduce the coefficient of *static* friction, μ_s;
- measure the angle θ_k at which a moving mass just *stops* sliding, and hence deduce the coefficient of *kinetic* friction, μ_k;
- calculate the ratio μ_k/μ_s.

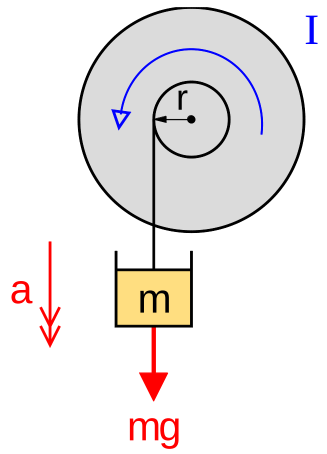
Repeat this for one of the objects with an additional mass on top to increase the normal reaction.

Object	Angle of incipient sliding, θ_s	Angle of incipient stopping, θ_k	Coefficient of static friction, μ_s	Coefficient of kinetic friction, μ_k	Ratio μ_k/μ_s
1					
2					
3					
Object + mass					

By considering the balance of forces, prove analytically the result $\mu = \tan\theta$ (applying to both static and kinetic friction).

Do you expect the ratio μ_k/μ_s to be the same for all materials? On what might it depend?

3. Flywheel Experiment



The *moment of inertia*, I, plays an analogous role in rotation to that which mass does in translation: resistance to change of motion.

In this experiment a falling weight is used to turn a flywheel. The time and distance of fall are measured. These are used to calculate the acceleration of the falling body and, thereby, the moment of inertia of the flywheel.

Method

A weight mg is attached to a string which is initially wrapped around the shaft of a flywheel. The shaft has radius $r = 0.011$ m (diameter 22 mm). The mass is allowed to fall from rest a distance h; the time taken, t, is measured with a stopwatch. A constant-acceleration formula relates the fall distance to the acceleration a:

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

In an ideal system, the linear acceleration, a, of the mass is related to the moment of inertia of the flywheel, I, and the acceleration due to gravity, g (=9.81 m s^{-2}), by

$$a = \frac{g}{1 + \dfrac{I}{mr^2}}$$

(You will derive this later in the lectures on rotation.) This can be rearranged for the moment of inertia:

$$I = mr^2\left(\frac{g}{a} - 1\right)$$

Find the final velocity v of the mass from another constant-acceleration formula and the final angular velocity ω of the flywheel by rearranging

$$v = r\omega$$

Check your calculations by comparing the loss of potential energy (mgh) with the gain in kinetic energy of the falling mass ($\frac{1}{2}mv^2$) and flywheel ($\frac{1}{2}I\omega^2$).

Repeat for different falling weights.

Results

Record your measurements in the following table.

mg (N)	h (m)	t (s)

$$I = mr^2\left(\frac{g}{a} - 1\right)$$

$$r = 0.011 \text{ m}$$

Analyse your results in the following table.

Mass m (kg)	Acceleration a (m s^{-2})	Moment of inertia I (kg m^2)	Final velocity v (m s^{-1})	Angular velocity ω (rad s^{-1})	Loss of PE mgh (J)	KE of mass $\frac{1}{2}mv^2$ (J)	KE of flywheel $\frac{1}{2}I\omega^2$ (J)

Comment on the energy changes in the experiment:

(1) Which types of energy are involved?

(2) Which forms of energy increase, and which decrease, during the motion?

(3) What can you say about the *relative* sizes of the kinetic energy of the mass and the flywheel?

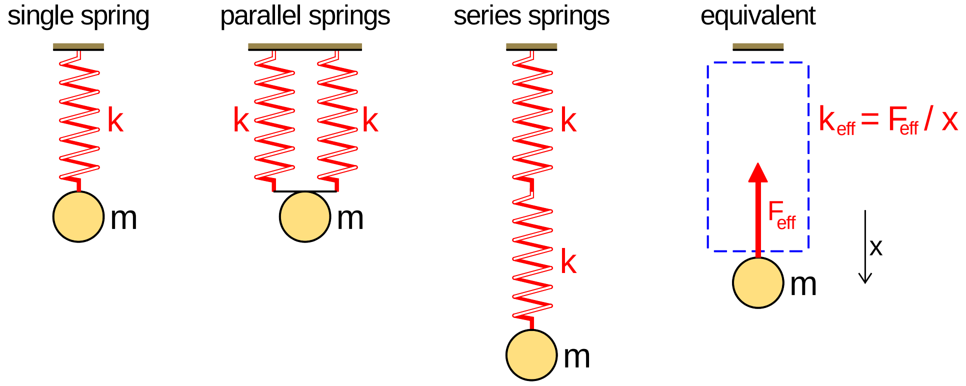
Suggest sources of error in the experiment and ways of eliminating them.

4. Oscillations

A mass m is hung from one or two equivalent springs in each of the configurations shown below. The period of oscillation T is compared with that predicted theoretically:

$$T = 2\pi\sqrt{\frac{m}{k_{\text{eff}}}}$$

where k_{eff} is the equivalent effective stiffness (the stiffness of a single spring that would have the same effect on the suspended load as a multi-spring configuration).



Method

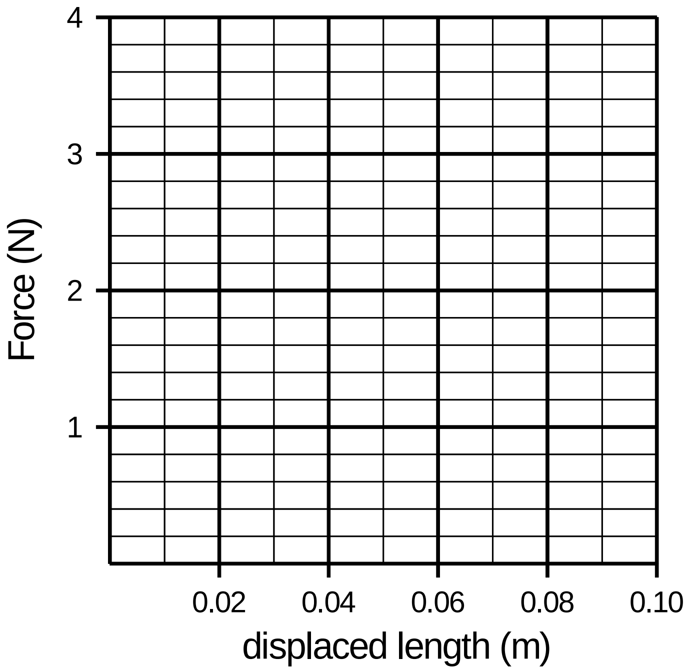
- By measuring the tension in a spring for different extensions, measure the stiffness k of a single spring. Force F and extension x are related by $F = kx$, and can be found as the *gradient* of a force vs length graph (simultaneously avoiding the need to find the unstretched length of the spring and testing the linear relationship, Hooke's Law).
- For each mass-spring configuration shown, measure the period of oscillation by timing a small number of oscillations. Try at least two masses for each combination.
- Compare measured periods with those predicted from mass m and stiffness k_{eff}.

Single spring stiffness.

Length (arbitrary datum) (m)	Force (N)

Stiffness (= gradient of line)

Run (m)	
Rise (N)	
Gradient (N m^{-1})	



Configuration:	Mass m (kg)	Measured period T (s)	Effective stiffness k_{eff} (N m^{-1})	Predicted period T_{pred} (s)
Single spring				
Parallel springs				
Series springs				

By noting the effective force F_{eff} on the mass for a given displacement of the mass, x, show how you deduce equivalent effective stiffnesses k_{eff} for:

– parallel springs:

– series springs:

Complete the table for measured and predicted oscillation periods.

Explain *physically* – i.e. *not* by appeal to the formula for period – which combination of mass (large or small) and effective stiffness (single, parallel or serial) you would expect to have the *shortest*, and which the *longest*, oscillation period and why.