Fundamental MECHANICS

Dynamics Fundamentals

CP1505
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Contents

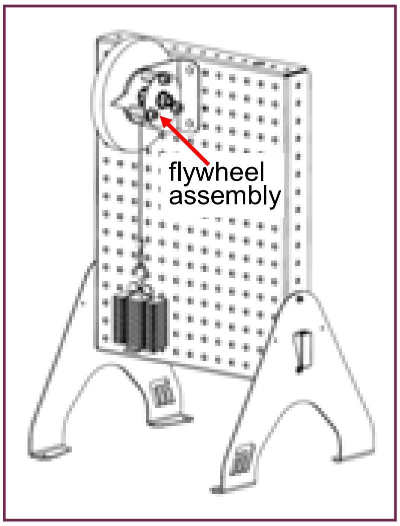
Worksheet 1
The flywheel

A flywheel is a heavy shaft-mounted disc which stores energy when it rotates.
For centuries, it has been used to store energy and to smooth rotation.
Today, flywheels, sealed in vacuum enclosures and rotating on magnetic bearings, are highly efficient at storing the output of intermittent energy sources, such as solar panels and wind turbines.

Over to you:

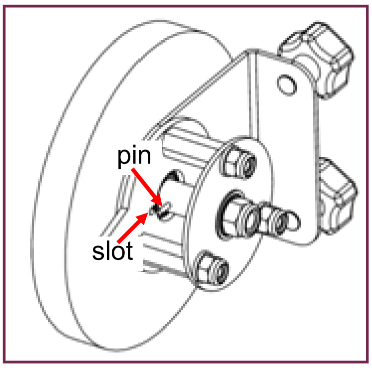
Setting up the apparatus:

The diagram shows the arrangement for this investigation.



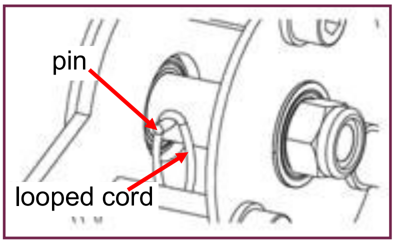
To construct the flywheel assembly:

- Slide the shaft through the holes in the main bracket.
- Rotate the shaft so that the pin can pass through the slot in the main bracket.
- Place the washer in position to hold the flywheel shaft.
- Tighten the nut on the shaft to keep the flywheel in place.



The flywheel assembly is then positioned at the top and in the middle of the work panel, to allow the maximum 'drop' for the weight.

- Place the empty mass hanger plus four slotted masses, a total mass of 100g (0.1kg), on the bench directly below the centre of the flywheel assembly.
- Make a cord 350mm long with loops on each end.
- Place one loop over the pin on the flywheel shaft.
- Connect the mass hanger to the lower loop.

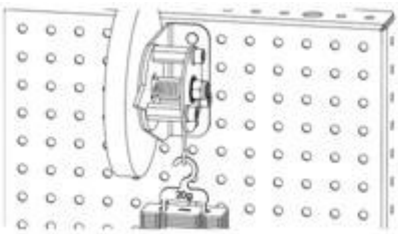


Worksheet 1

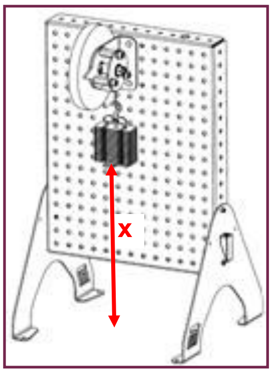
The flywheel

Over to you .....

- Turn the flywheel to coil the string around the shaft and raise the mass hanger to just below the flywheel assembly.



- Measure height, **x**, of the empty mass hanger above the bench top.



- Release the mass hanger and time how long it takes to reach the bench.
- Repeat this three times and calculate the average time.
- Record these measurements in the Student Handout.

- Increase the mass of the hanger to 200g (0.2kg).
- Repeat the process, timing three falls as before and working out the average.
- Record these measurements in the Student Handout.

- Increase the mass of the hanger in two further 100g steps to a maximum of 400g (0.4kg).
- Repeat the process described above and record the measurements in the Student Handout.

Worksheet 1

The flywheel

So what:

From equations of motion: $\mathbf{s} = 1/2\ \mathbf{a} \times \mathbf{t}^2$

where: $\mathbf{s}$ = distance travelled,

$\mathbf{a}$ = acceleration

$\mathbf{t}$ = time of flight

In this case: $\mathbf{s} = \mathbf{x}$

$\mathbf{t}$ = *average* time of flight

and so, the acceleration of mass hanger,

$$\mathbf{a} = 2 \times \mathbf{x} / \mathbf{t}^2$$

The force needed to produce this acceleration is given by:

$\mathbf{F} = \mathbf{m} \times \mathbf{a}$ where $\mathbf{m}$ = mass of falling hanger.

This force comes from the gravitational pull on the hanger, i.e. its weight **W**, where

$\mathbf{W} = \mathbf{m} \times \mathbf{g}$ where $\mathbf{g}$ = acceleration due to gravity = $9.8 m.s^{-2}$

The remainder of this weight generates a torque, τ, that increases the angular acceleration of the flywheel.

In other words, $\tau = [(\mathbf{m} \times \mathbf{g}) - (\mathbf{m} \times \mathbf{a})] \times \mathbf{r}$ where $\mathbf{r}$ = radius of the shaft = 8mm

The angular acceleration of the flywheel, α, is given by the equation:

$$\alpha = \mathbf{a} / \mathbf{r}$$

It is related to the torque by the equation:

$\tau = \mathbf{I} \times \alpha$ where $\mathbf{I}$ = moment of inertia of the flywheel

This equation predicts that a graph of torque, τ, vs angular acceleration, α, will produce a straight line with a gradient of **I**, the moment of inertia of the flywheel.

- In the Student Handout, use the grid provided to plot a graph of torque, τ, vs angular acceleration, α and use it to obtain a value for the moment of inertia of the flywheel.
- Then calculate the theoretical value of this moment of inertia and use that to calculate the final angular velocity of the flywheel in $rad.s^{-1}$ and $revs.s^{-1}$.

In practice:

A flywheel's capacity to store energy depends on its mass and its rotational speed. Modern flywheels are made of lightweight, high strength materials because while doubling its mass doubles its kinetic energy, doubling its rotational speed quadruples it.

Worksheet 2

Controlling friction

Friction - sometimes a blessing, sometimes a curse!

Without it:

- we couldn't walk or run;
- cars wouldn't move and if they did, wouldn't stop;
- trains would slip endlessly on railway lines;
- ladders would slide down walls.

However, because of it:

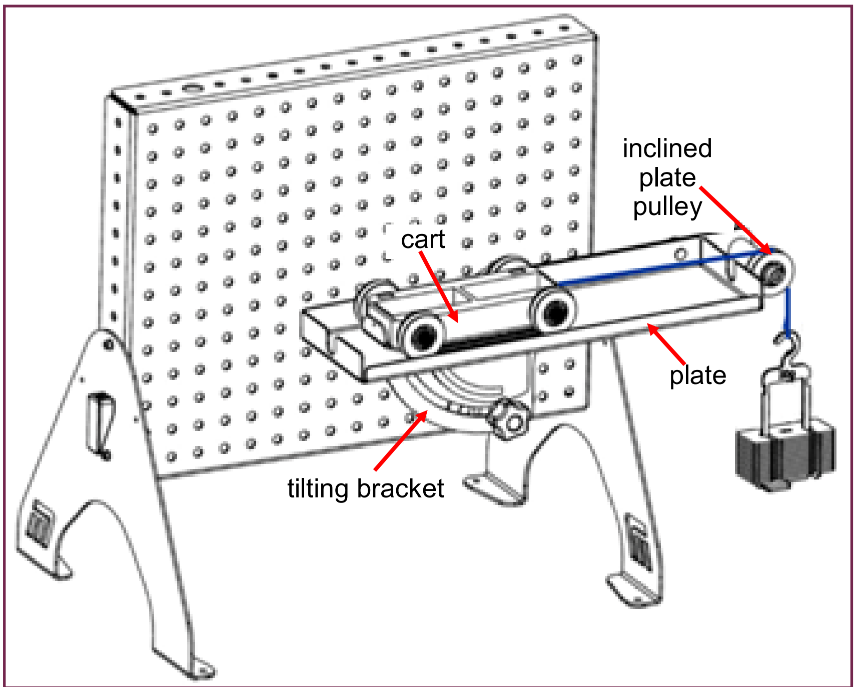
- vehicles use more fuel;
- the range of aircraft is reduced;
- bearings in machinery heat up and wear out.

1. Types of friction

Over to you:

Setting up the apparatus:

The diagram shows the apparatus arrangement for this investigation.



To construct the inclined plane assembly:

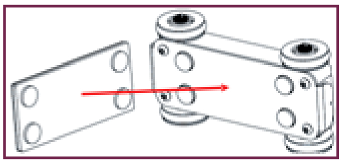
- fasten the plate to the tilting bracket with the two bolts;
- fasten the pulley to the end of the tilting bracket;
- connect the inclined plane assembly to the work panel in the position shown;
- adjust the cord attached to the cart by creating a loop just below the pulley.

Worksheet 2

Controlling friction

Over to you .....

- Adjust the inclined plane until it is horizontal (i.e. the pointer indicates zero degrees) and clamp it in position.
- Attach the metal plate to the bottom of the cart using the Velcro tabs, as shown opposite.



- Place the cart on the empty plate with its wheels in contact with the plate.
- Add the empty mass hanger to the loop hanging over the pulley.
- Place slotted masses, one at a time, on the mass hanger until the cart starts to move. (This requires a very steady hand!
  Tap the work panel gently to remove the effect of static friction!)
- In the Student Handout, record the weight needed to start the cart moving. This indicates the frictional force holding the cart stationary.
  (If the cart moves when the mass hanger is empty, record this as “<0.2N.)
- Now repeat the process with the car turned upside down, i.e. metal plate in contact with metal plate, a metal / metal contact. Notice that the mass of the cart remains unchanged.

Challenge!

Repeat the experiment using different materials attached to the cart and different materials inside the plate. Hence explore the frictional forces between the following combinations:

wood / wood   wood / metal   wood / rubber   metal / metal   metal / rubber   rubber / rubber

So What?

The results show some of the factors affecting frictional forces between surfaces in contact.

Once the cart starts to move, it accelerates, since the frictional force it experiences while moving, called sliding friction, is smaller than the one it experienced when stationary, called static friction. This means that once an object is moving, its much easier to keep it moving.

The size of the frictional forces depends on the materials in contact.

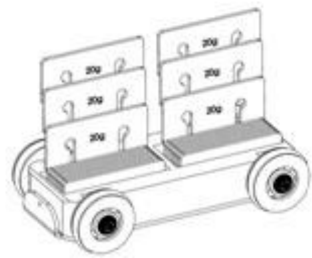
Controlling friction is of huge importance in applications such as automotive engineering.

2. Static and sliding friction

Over to you:

The apparatus is set up as in the previous investigation, but this time, the materials remain the same, but the mass of the cart is changed to see what effect this has.

- Clamp the plate in a horizontal position and place the wooden floor in it.
- Attach the wooden plate to the bottom of the cart using the Velcro tabs.
- Weigh the cart on the force meter and record its weight in the Student Handout.
- Place the cart on the plate so that the wooden plate is in contact with the wooden floor. The floor provides an upward reaction force equal to the weight of the cart, acting normal to the surface - i.e. the *normal force* is the weight of the cart.
- Add the empty mass hanger to the loop hanging over the pulley.
- Place slotted masses on the mass hanger, one at a time, until the cart starts to move. At this point, the weight on the hanger equals the *frictional force* between cart and floor. (This time, do not tap the work panel. Take care not to disturb the bench in any way.) In the Student Handout, record the ***weight*** of the hanger needed to start the cart moving.
- Now increase the weight of the cart by 2N by placing ten slotted masses in it.
- Repeat the procedure and record the hanger weight needed to start the cart moving now.



So What?

- Static friction, more commonly known as ‘stiction’, is caused by attractive forces between the molecules of the materials placed in close contact.
- Surface roughness increases this effect.
- The size of the frictional force depends on the coefficient of static friction, μ_S, between the materials. This is the ratio of the frictional force to the normal force.
- Use your results to calculate two estimates for μ_S, between the wooden plates.

Challenge!

- Repeat the experiment for different pairs of materials to determine the coefficient of static friction between them.
- Carry out a more extensive investigation into the coefficient of static friction between two materials by progressively adding more and more weight to the cart and measuring the static frictional force each time. A graph of the normal force (weight of the cart) against the static frictional force (hanger weight needed to start it moving) should produce a straight line graph whose gradient gives the coefficient of static friction between the two materials.

3. Angle of friction

Over to you:

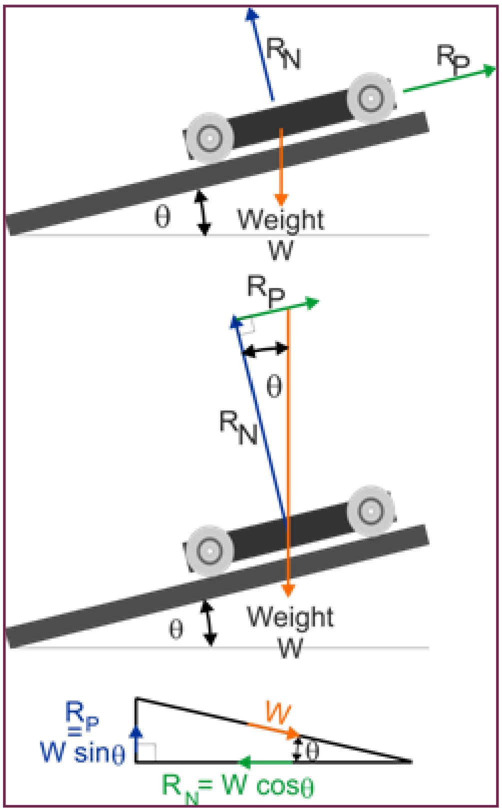
- The apparatus is the same as in previous investigations.
- Adjust the plate until it is at an angle of 5^0 to the horizontal.
- Remove the wooden friction plate from the cart and replace it with the metal one.
- Place the cart at the top of the slope with the rope stored inside it.
  There is no mass hanger attached this time.
- Gently tap the work panel to remove the effect of static friction.
- Slowly and very carefully, increase the angle of the plate until the cart slides smoothly down it.
- In the Student Handout, record the angle, θ, at which this happens and hence calculate the coefficient of *sliding* friction, μ_K.

So What?

The minimum angle at which the cart slides down the plate can be used to determine the coefficient of *sliding* friction, μ_K.

The diagrams show the forces acting on the cart:

- its weight, **W**;
- the normal (i.e. perpendicular) reaction, $\mathbf{R_N}$;
- the parallel reaction, $\mathbf{R_P}$ due to friction.



The middle diagram shows the result of applying the triangle of forces rule. This creates the triangle shown at the bottom and trigonometry leads to the results:

$\mathbf{R_N} = \mathbf{W} \cos\theta$ and $\mathbf{R_P} = \mathbf{W} \sin\theta$

The coefficient of sliding friction, μ_K, is defined by:

$$\mu_K = \frac{\mathbf{R_P}}{\mathbf{R_N}} = \frac{\mathbf{W} \sin\theta}{\mathbf{W} \cos\theta} = \frac{\sin\theta}{\cos\theta} = \tan\theta$$

Your results can be used to work out the coefficient of sliding friction between metal surfaces.
Notice that the weight of the cart does not affect the result in this test because it is cancels out in the equation for the coefficient of friction.

Challenge!

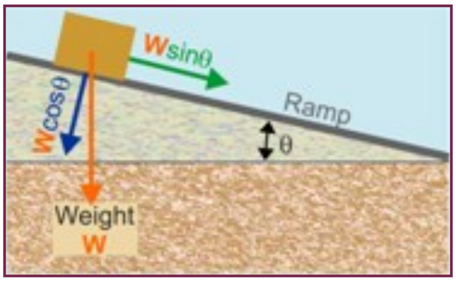
Repeat the experiment for different pairs of materials and hence determine the coefficient of sliding friction between them.

Worksheet 3

Inclined forces

When an object sits on a ramp, its weight is trying to do two things:

- press it into the ramp's surface;
- push it down the ramp.



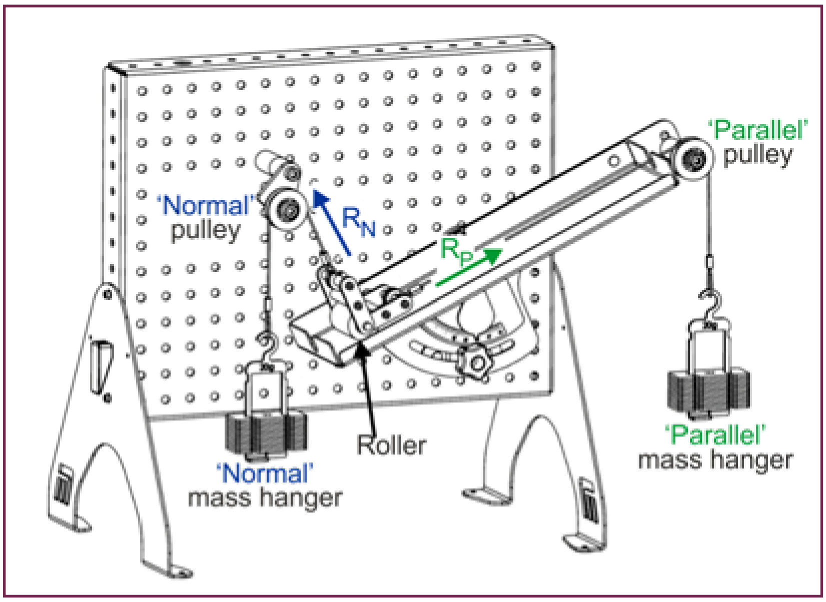
The diagram shows that the forces involved depend on the angle, θ, of the ramp. The force pressing into the surface is $W\cos\theta$ and that trying to push it down the ramp is $W\sin\theta$, where W is the weight of the object.

The aim of this investigation is to measure these two components of the object's weight.

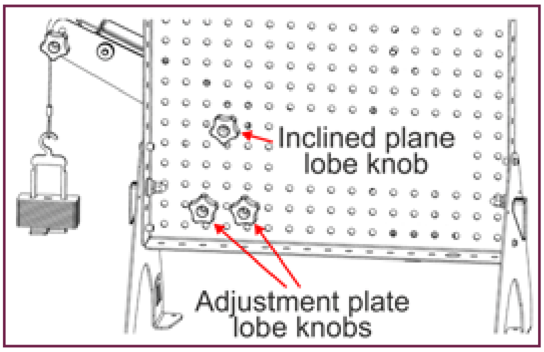
Over to you:

Setting up the apparatus:

The diagram shows the setup for this investigation:



- Clamp the work panel in 'landscape' orientation.
- Fasten the centre of the plate four holes from the right hand edge of the work panel.



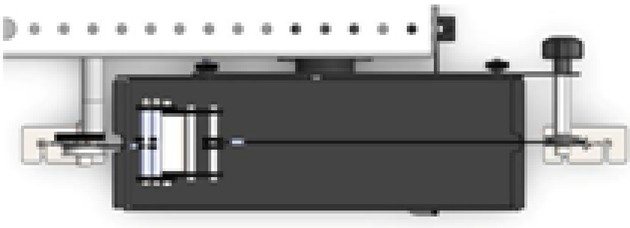
- With the plate horizontal, fix the adjustment plate assembly four holes lower, so that the two lobe knobs are separated by one column of holes.
- Attach the 'Normal' pulley in the position shown.
- Check that the 'Parallel' pulley is sitting at the bottom of the adjustment slot so that the string sits parallel to the surface of the plate.

Worksheet 3

Inclined forces

Over to you .....

- Weigh the roller assembly on the force meter and record it in the Student Handout.
- Tilt the plate to an angle of 20^0 and tighten the lobe nuts to hold it there.
- Place the roller at the bottom of the slope and hang the two cords over the pulleys.
  The pulleys and cords should line up as in the diagram.



- Hang the 'Normal' mass hanger and the 'Parallel' mass hangers in place.
- Slowly add weights to each hanger until the roller just lifts off the plane and the two strings connected to the roller form a right angle.
- Use the smaller value weights to make fine adjustments.
  At this point, the 'Normal' force, R_N, is equal to the weight of the 'Normal' mass hanger and the 'Parallel' force, R_P, is equal to the weight of the other hanger.
- Record both hanger weights in the Student Handout.
- Repeat this procedure for plate inclinations of 30^0, 40^0 and 50^0, recording all results in the Student Handout.
  (As the inclination increases, the 'Normal' pulley may have to be moved to keep the mass hanger away from the plate and keep the looped string perpendicular to it.)

So What?

- Calculate the theoretical values for the 'Normal' and 'Parallel' components and hence complete the table in the Student Handout. (The roller weighs 1.8N)
- Compare these values with those measured experimentally .
- Try to explain any discrepancies by considering possible sources of error, and record your ideas in the space provided in the Student Handout.

As the inclination of the plate increases, more of the weight of the object is transferred to the 'Parallel' force, trying to push to object down the slope, and less to the 'Normal' component, pushing it into the surface.
When the plate is vertical, the 'Normal' component is zero and the 'Parallel' component equals the full weight of the object.
When the plate is horizontal, the situation is reversed. There is no force trying to push the object along the plate.

Not a surprising result for pedestrians!
After all, the steeper the slope, the more likely you are to slide down it!

Worksheet 4

Pulley systems

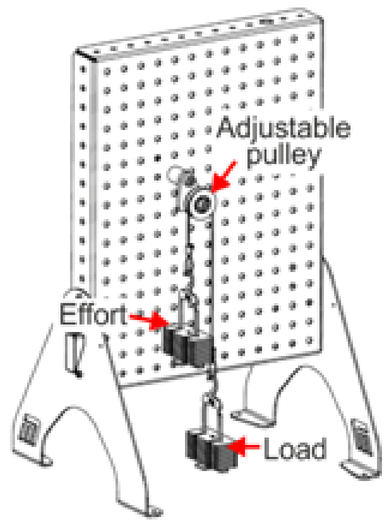
A pulley is a simple machine, designed to make a task easier.
It can change the direction in which a force needs to act.
It may make it easier to lift an object.

They have been used for centuries, to raise containers of water, hoist sails on sailing ships, perhaps even lift the stones that make up the great pyramids in Egypt.

However, a pulley cannot generate energy. In reality, it wastes it but in doing so make the task easier to perform. Apart from friction between moving parts, it usually involves lifting the pulley itself and the cables passing over it, all of which takes energy.

1. A change in direction:

The diagram shows the setup used in the next investigation:



Over to you:

- Clamp the work panel in ‘portrait’ orientation.
- Fix the adjustable pulley as shown in the diagram.
- Arrange two empty mass hangers, connected by a cord passing over the pulley.
- Add four slotted weights to the right-hand hanger, giving the ‘Load’ a total mass of 100g (i.e. a weight of 1N).
- Slowly increase the weight of the ‘Effort’ mass hanger, from 0.2N (one slotted mass) to 1.2N (five slotted masses).
- In the Student Handout, describe what happens as you do so.
- Remove the ‘Effort’ mass hanger, while holding onto the cord. Notice how hard you need to pull to raise the load.

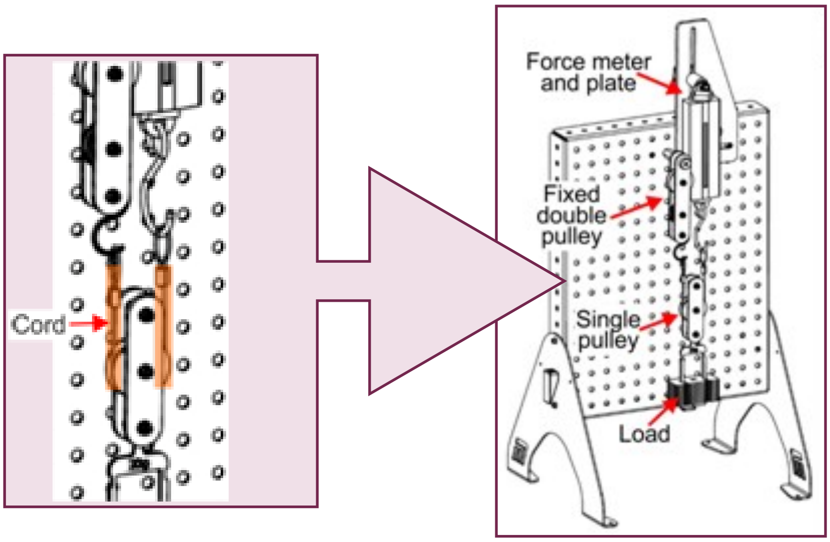
So What?

This arrangement creates no force multiplication (i.e. its mechanical advantage = 1), though, equally, the velocity ratio is 1 - both load and effort travel the same distance.

There may be an advantage in using this approach where a worker is hoisting a load up a building. The worker’s bodyweight can be used as part of the effort.

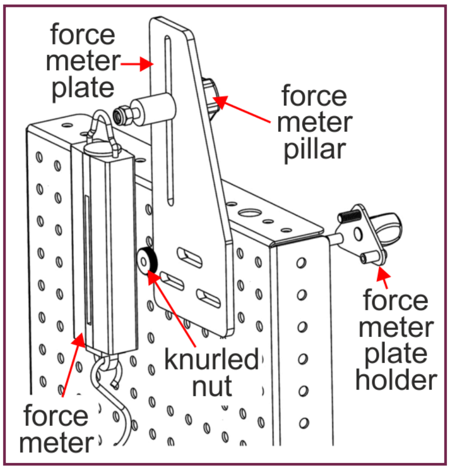
2. Force multiplication:

The setup is changed to the one shown below:



Building the force meter assembly:

The diagram below shows the force meter plate and fixtures:



- Secure the force meter plate holder to the work panel in the chosen position, with the threaded stud uppermost.
- Place the force meter plate over the plate holder and fix it in place using the knurled nut.
- Attach the force meter pillar as shown in the diagram.
- Hang the force meter on the rod protruding from the force meter pillar.

2. Force multiplication .....

- Place the fixed double pulley assembly in the middle near the top of the work panel.
- Then position the force meter and plate just to the side of the pulleys.
- Attach an S-hook to the bottom of the double pulley, thread the cord through the single pulley and hang the loops over the hooks, as shown in the detail above.
- Hook an empty mass hanger onto the bottom of the single pulley.
- ‘Zero’ the force meter to eliminate the weights of the pulley and empty hanger.
- Add five slotted weights to the empty mass hanger to increase the load by 1N.
- Record the reading on the force meter, the effort in this case, in the Student Handout.
- Increase the load by adding two more slotted weights, 0.4N and record the new effort.
- Continue in this way until the load reaches 3N.
- Complete the table by calculating the mechanical advantage for each value of load.
- Unhook the force meter and instead pull up on the cord to see how hard you need to pull to raise the load.

So What?

This arrangement shows that a pulley that can move, rather than be fixed, like the one in the previous experiment, can offer force multiplication - here only half the effort is needed to lift the same load. This equates to a mechanical advantage of 2.

However, there can be no energy multiplication!

In other words:

work done by effort = work done by load in an ideal system,

i.e.effort x distance moved by effort = load x distance moved by load

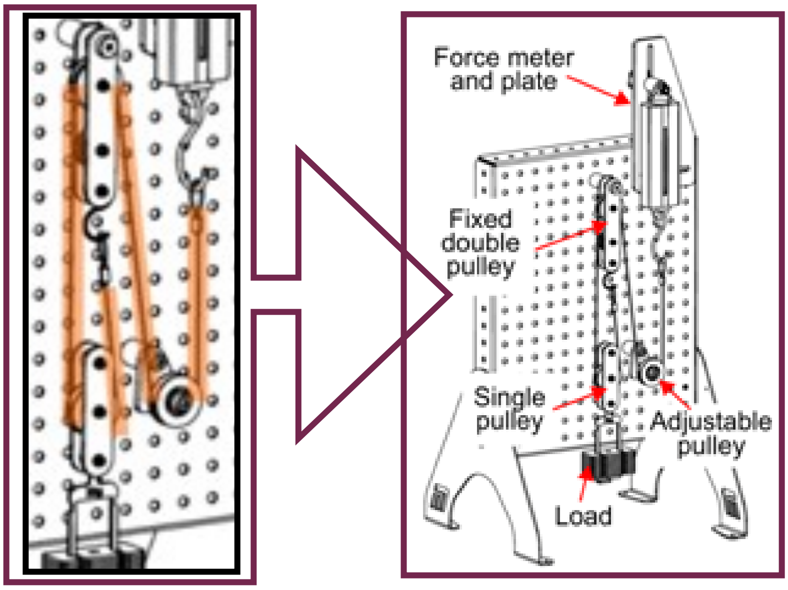
In real systems, the work done by the effort is always larger than that done by the load,

and effort x effort distance = load x load distance + work done to overcome friction.

In other words, the energy efficiency is less than 100%

3. Force multiplication - the same but different:

- Now modify the setup slightly by moving the force meter and plate to the right to allow room for the adjustable pulley:



- Fix the adjustable pulley directly below the force-meter near the bottom of the work panel.
- The procedure is exactly the same as in the previous experiment:
  - ‘Zero’ the force meter to eliminate the weights of the pulleys and empty hanger.
  - Add slotted weights to increase the load by 1N.
  - Record the effort reading on the force meter in the Student Handout.
  - Increase the load by 0.4N and record the new effort.
  - Continue in this way until the load reaches 3N.
  - Complete the table in the Student Handout by calculating the mechanical advantage for each value of load.
- Finally, unhook the force meter and instead pull up on the cord to see how hard you need to pull to raise the load.

So What?

This setup looks more potent, but it still has a mechanical advantage of 2.

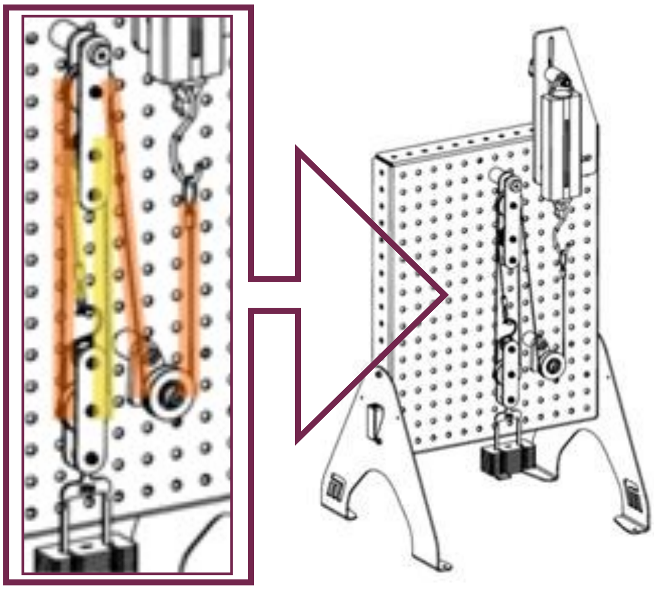
The adjustable pulley means that the direction of the effort can be changed, often an advantage in that it allows the system designer more flexibility.

Worksheet 4

Pulley systems

4. Force multiplication - even bigger:

- The hardware is set up as in the last experiment but the stringing is different. Notice that, this time, five strings pass between and around the pulleys. Last time, it was four.



- The extra string is the loop over the lower pulley on the fixed pulley assembly, connected to the top of the free single pulley, (highlighted in yellow.)
- The procedure is exactly the same as before:
    - ‘Zero’ the force meter to eliminate the weights of the pulleys and empty hanger.
    - Add slotted weights to increase the load by 1N.
    - Record the effort reading on the force meter in the Student Handout.
    - Increase the load by 0.4N and record the new effort.
    - Continue in this way until the load reaches 3N.
    - Complete the table in the Student Handout by calculating the mechanical advantage for each value of load.
- Finally, unhook the force meter and instead pull up on the cord to see how hard you need to pull to raise the load.

So What?

The mechanical advantage of this arrangement is bigger and so a heavier weight can be lifted with less effort.

The bigger number of loops causes more friction and so the efficiency of the system is lower.

Worksheet 5

The toggle mechanism

All mechanical systems have design limits beyond which they should not pass - just ask the athlete in the photograph.

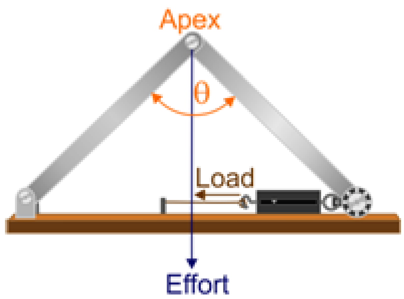
This applies to dynamics as well. This investigation looks at the performance of a spring-loaded toggle mechanism. Some applications, such as toggle switches, are designed to operate at these limits.

The idea:

The diagram illustrates the principle.

The force meter spring exerts a force that prevents the mechanism from collapsing. Should this force, known as the load in this case, increase, the apex of the toggle mechanism starts to drop and angle θ increases.

Increasing the effort counteracts this (i.e. reduces angle θ).



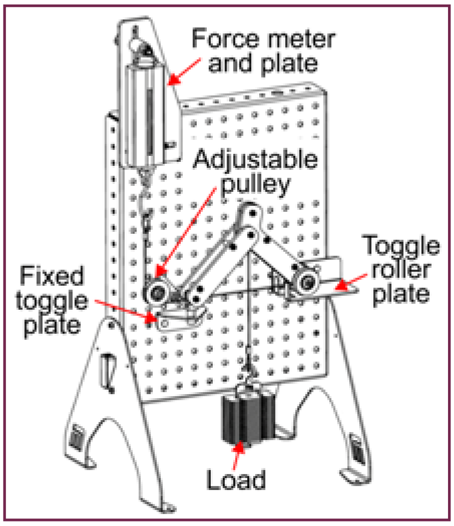
Over to you:

Setting up the apparatus:

The diagram shows the setup for this investigation:

- Fasten the force meter and plate in the top left corner of the panel, with the screw placed four rows down from the top and one row in from the left-hand side.
- Position the adjustable pulley directly below the force meter with its screw in 'row 8', 'column 3', shown in the detail diagram. This needs to be fastened tightly.
- The fixed toggle plate is attached with screws in 'row 4', 'columns 3 and 5'.
- The toggle roller plate is placed with the screws in 'row 6' columns 11 and 13'.
- Loop the cord from the toggle roller onto the force meter hook, via the adjustable pulley.

  Allow the other cord to hang down from the centre of the toggle mechanism.



- Adjust the first cord so that the apex of the mechanism forms roughly a right-angle, when the toggle rollers are close to, but not touching, the end stops of the toggle roller plate.

Worksheet 5

The toggle mechanism

Over to you .....

- Place an empty mass hanger on the cord hanging down from the centre of the toggle mechanism.
- Press down gently on the apex of the toggle. The angle θ increases. As it approaches 180^0, the mechanism 'snaps' downwards and locks - the toggle 'snap' action.
- 'Zero' the force meter.
- Gently, add two slotted masses (i.e. add 0.4N) to the mass hanger.
- Tap the work panel gently until the force meter gives a consistent reading.
- Record the force meter reading in the corresponding row of the 'load' column in the table in the Student Handout.
- Increase the weight on the hanger by 0.4N (another two slotted masses) and repeat the process.
- Continue in this way until the weight added to the hanger is 3.2N.
- Repeat the series of readings to improve overall accuracy.
- Use these results with the axes and grid provided in the Student Handout to plot a graph of load against effort. (Do not expect a linear result!)

Challenge!

Investigate the effort needed to make the mechanism 'snap'.

So what:

The distance that the apex of the mechanism falls vertically is larger than the distance the toggle rollers move horizontally. This behaviour implies that the system offers a mechanical advantage.

The output force increases as the effort force increases. This means that a small increase in the effort can produce a large change in the output force when the toggle mechanism is nearing the end of its possible movement.

The mechanism 'snaps' into a locked position when it goes over the 'top dead centre' (TDC) point. Thereafter, the toggle mechanism exerts a constant output force.

This mechanism has a range of useful applications, from toggle switches through car jacks and oil-well pumps, to rock-crushing equipment.

Student Handout

Student Handout

Fundamental MECHANICS

Worksheet 1 - The flywheel

Distance **x** above bench top = ...mm = ...m

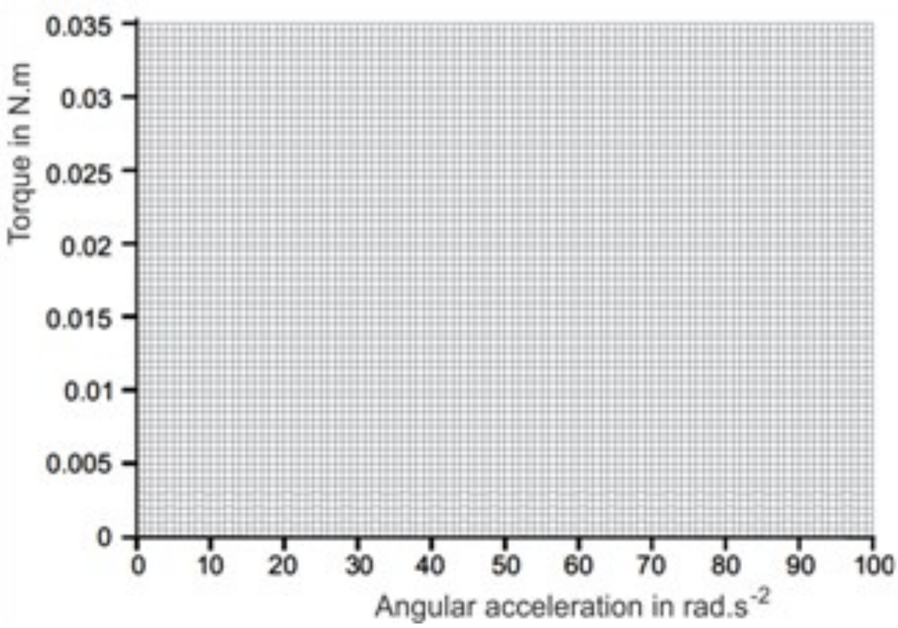
Falling mass in kg	Flight time			
	measurement 1 in s	measurement 2 in s	measurement 3 in s	average in s
0.1				
0.2				
0.3				
0.4				

Use your measurements to complete the following table:

Falling mass m in kg	Average flight time t in s	Linear acceleration a in $m.s^{-2}$	Angular acceleration α in $rad.s^{-2}$	(m.g - m.a) in N	Torque in N.m
0.1					
0.2					
0.3					
0.4					

Graph of torque vs angular acceleration:

Show your measurements as small crosses. Use them as a guide to position a straight line passing through the origin.



Moment of inertia of flywheel = gradient of graph = ...

Student Handout

Worksheet 1 - The flywheel .....

Calculate the theoretical moment of inertia for cylinder, like the flywheel using:

$$I = \frac{M \times R^2}{2}$$

where **M** = mass of flywheel = 1.45kg

R = radius of flywheel = 65mm = 0.065m

....

....

....

Calculated value for the moment of inertia, **I**, is ....kg.m^2

The gravitational potential energy lost by the falling mass hanger, E_P is given by:

$$E_P = m \times g \times x$$

Calculate the gravitational potential energy lost by the 400g mass hanger as it fell:

= ....J

This is converted into kinetic energy of rotation, E_K of the flywheel.

Calculate the theoretical final angular velocity of the flywheel using the formula:

$$E_K = 1/2\ I\ \omega^2$$

....

....

....

Use the fact that there are 2π radians in one revolution to convert this to show the rotational speed of the flywheel in revs / second.

....

....

In practice, E_K will not be equal to E_P.

Explain why:

....

....

....

....

....

....

Student Handout

Worksheet 2 - Controlling friction

1. Types of friction

Test surfaces	Hanger weight in N	Horizontal force in N
wheels		
metal-metal		

(The blank rows are for the results of the Challenges.)

2. Static and sliding friction

Weight of cart in N (i.e. normal force)	Hanger weight in N (i.e. frictional force)	Coefficient of static friction μ_s
(empty)		
(+ 2N)		

Wood / wood contact:

Weight of cart in N (i.e. normal force)	Hanger weight in N (i.e. frictional force)	Coefficient of static friction μ_s
(empty)		
(+ 2N)		

Challenge: .... contact:

Weight of cart in N (i.e. normal force)	Hanger weight in N (i.e. frictional force)

Comprehensive investigation: .... contact:

Student Handout

Worksheet 2 - Controlling friction

3. Angle of friction

Test surfaces	Plate angle θ	$\mu_K = \tan\theta$
metal-metal		
metal-wood		
wood-wood		
rubber-wood		

Worksheet 3 - Inclined forces

Measured values:

Weight of roller, W = ...N

Plate angle θ	'Normal' mass hanger load in g	Normal reaction force R_N in N	'Parallel' mass hanger load in g	Parallel reaction force R_P in N
20^0				
30^0				
40^0				
50^0				

Calculated values:

(using $R_N = W\cos\theta$ and $R_P = W\sin\theta$)

Plate angle θ	Normal reaction force R_N in N	Parallel reaction force R_P in N
20^0		
30^0		
40^0		
50^0		

Comparison of measured and calculated values:

....

....

....

....

....

....

Student Handout

Fundamental MECHANICS

Worksheet 4 - Pulley systems

1. A change in direction:

What happened as you increased the weight of the 'Effort' mass hanger?

....

....

....

....

....

....

2. Force multiplication:

Load in N	Effort in N	Mechanical advantage
1.0		
1.4		
1.8		
2.2		
2.6		
3.0		

3. Force multiplication - the same but different:

Load in N	Effort in N	Mechanical advantage
1.0		
1.4		
1.8		
2.2		
2.6		
3.0		

4. Force multiplication - even bigger:

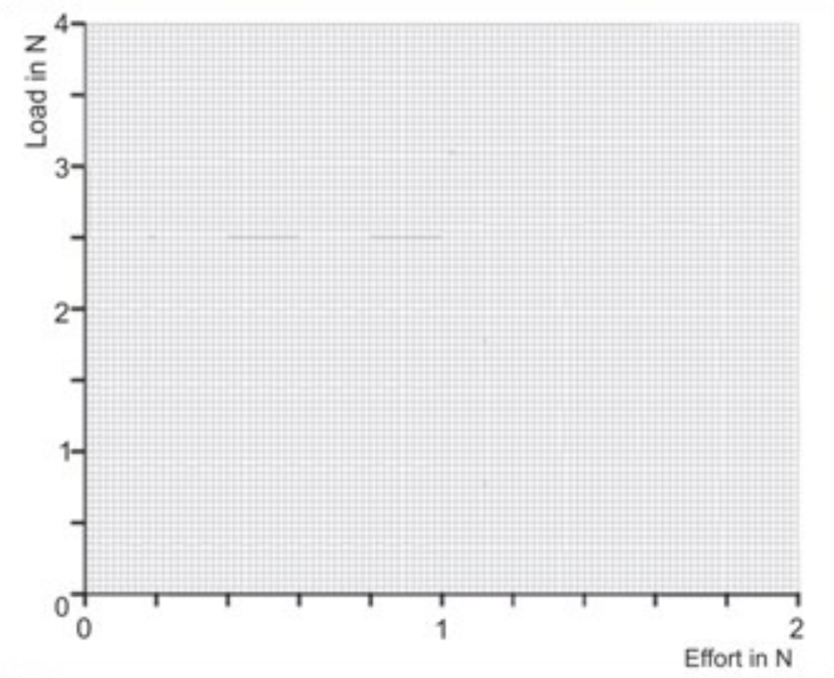
Load in N	Effort in N	Mechanical advantage
1.0		
1.4		
1.8		
2.2		
2.6		
3.0		

Student Handout

Worksheet 5 - The toggle mechanism

Effort in N	Load in N		
	1st attempt	2nd attempt	3rd attempt
0.4			
0.8			
1.2			
1.6			
2.0			
2.4			
2.8			
3.2			

Relationship between forces in the toggle mechanism:



Challenge!

What effort force causes the mechanism to 'snap'?

....

Notes
for the
Instructor

Notes for the instructor

About this course

Introduction

The ‘Fundamental Mechanics - Dynamics’ module introduces students to the relationship between the applied forces and resulting motion for a number of common engineering mechanisms.

The kit can assembled by the students and used with minimum supervision to complete a series of worksheets that illustrate a number of topics relevant to BTEC National and Higher National courses.

Aim

The course teaches students to investigate factors which determine the motion of mechanisms commonly used in engineering.

Prior Knowledge

It is expected that students have followed an introductory science course, enabling them to take, record and analyse scientific observations. Some mathematical capability is required - ability to take readings from an analogue scale, ability to understand the transposition of formulae, ability to use a calculator to perform calculations and ability to plot a graph.

Using this course:

It is expected that the Worksheets and Student Handout are printed / photocopied, preferably in colour, for the students’ use.

The worksheets have:

- an introduction to the topic under investigation;
- step-by-step instructions for the investigation that follows
- a guide to analysing the results.

The Student Handout is a record of measurements taken in each worksheet and questions relating to them. Students do not need a permanent copy of the worksheets but do require their own copy of the Student Handout

This format encourages self-study, with students working at a rate that suits their ability. It is for the instructor to monitor that their understanding is keeping pace with progress through the worksheets. One way to do this is to ‘sign off’ each worksheet, as the student completes it, and in the process have a brief chat to assess the student’s grasp of the ideas involved in the exercises it contains.

We realise that you as a subject area practitioner are the lead in determining how and what students learn. The worksheets are not meant to supplant this or any other supporting underpinning knowledge you choose to deliver.

For subject experts, the ’Notes for Instructors’ are provided simply to reveal the thinking behind the approach taken. For staff whose core subject knowledge is not in the field covered by the course, these notes can both illuminate and offer guidance.

Time:

It will take students between three and five hours to complete the worksheets.
A similar length of time will be needed to support the learning that takes place as a result.

Notes for the instructor

What the student will need:

To complete the course, the student will need the following equipment:

Bom Structure	Description	Quantity
FM3935	Dynamics for Fundamentals kit	
COM1488	Tray friction plate large rough	1
COM7488	Salter 12 spring balance 10N x 0.1N	1
FM0255	Single Pulley Assembly	1
FM1016	Flywheel Assembly	1
FM1566	Friction assembly (rough surface)	1
FM2222	Balance Slider Plate Assembly	1
FM2522	Work Panel for Fundamentals	1
FM2666	5g hanging weights pack of 5	2
FM2915	Hanging Weights	2
FM3322	Toggle Assembly	1
FM4503	Adjustable Plate Assembly	1
FM4759	Single Parallel Pulley Assembly	1
FM6213	Double Pulley Assembly	1
FM6438	Inclined Plate Pulley Assembly	1
FM6508	RH Adjustable Pulley Assembly for FM1883	1
FM6737	Spring Balance Pillar	1
FM6908	LH adjustable pulley assembly for the FM1883	1
FM7405	Looped String kit for FM3935	1
FM7411	Friction assembly (wood)	1
FM8871	Toggle Travel Plate	1
FM9550	Inclined Tray Assembly	1
FM9574	3D Printed Cart	1
FM9811	Friction assembly (stainless steel) for FM3935	1
FM9852	Roller Assembly	1
HP2045	Plastic shallow tray BLACK	1
HP3844	Thin foam tray insert 355x270x5mm	3
HP4039	Tray Lid	2
HP5540	Deep tray	1
HP8600	Crash Foam 360mm x 260mm, thickness 25mm	3
HP9564	62mm daughter tray	1
LAS1438	Tray friction surface plate wood(large) for FM3935	1
LAS1488	Laser cut foam for packaging of FM3935	1
LAS1499	Spring balance mounting plate for FM1883	1
MET1360	Stainless Steel plate large for friction assemblies	1

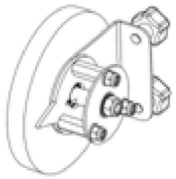
Notes for the instructor

Fundamental MECHANICS

What the student will need, worksheet by worksheet:

Worksheet	Item
1	work panel
	flywheel assembly
	mass hanger
	looped cord
2	work panel
	inclined plate assembly
	cart
	inclined plate pulley
	mass hanger
	metal / wood / rubber friction plates
3	work panel
	inclined plate assembly
	roller assembly
	long adjustable pulley
	inclined plate pulley
	mass hanger
4	work panel
	adjustable pulley
	single pulley
	double fixed pulley
	force meter
	force meter plate
	two mass hangers
	looped cord
5	adjustable pulley
	force meter
	force meter plate
	fixed toggle plate
	toggle roller plate
	toggle mechanism
	mass hanger

Identity parade:


flywheel assembly

mass hanger


inclined plate assembly


force meter plate


friction plate


cart


adjustment for inclined plate

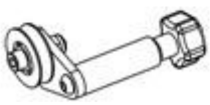

force meter

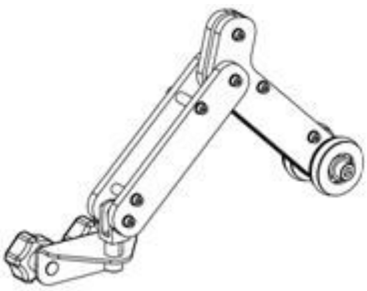

force meter plate holder

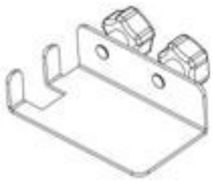

adjustable


force meter pillar

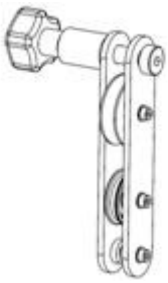

roller assembly


long adjustable pulley


toggle mechanism


toggle roller plate


single pulley


double pulley

Notes for the instructor

Learning Objectives for chapter 1

On successful completion of this course, the student will be able to:

- describe the energy changes that take place when a falling weight causes a flywheel to rotate;
- use a value for gravitational field strength to calculate the weight of a given mass;
- explain the meaning of the following terms:
    - torque;
    - moment of inertia;
    - angular velocity;
    - angular acceleration;

  and identify the corresponding quantities in linear motion;
- use a graph of torque vs angular acceleration to obtain a value for the moment of inertia;
- use the formula $I = ½ (\mathbf{M} \,.\, \mathbf{R}^2)$ to calculate the moment of inertia of a flywheel;
- use the formula $\mathbf{E_P} = \mathbf{m} \,.\, \mathbf{g} \,.\, \mathbf{x}$ to calculate the loss in gravitational potential energy of a falling mass;
- use the formula $\mathbf{E_K} = ½(\mathbf{I} \,.\, \omega^2)$ to calculate the kinetic energy of a spinning flywheel.

Learning Objectives for chapter 2

On successful completion of this course, the student will be able to:

- distinguish between static and sliding friction;
- describe an experiment designed to measure both the static and sliding frictional force between two surfaces;
- explain why gently tapping the bench improves the accuracy of a measurement of sliding friction;
- use the formula μ_s = frictional force / normal force to calculate the coefficient of static friction;
- use a graph of frictional force vs normal force to obtain a value for the coefficient of static friction;
- resolve a force into two perpendicular components using $\mathbf{R_N} = \mathbf{W} \cos \theta$ and $\mathbf{R_P} = \mathbf{W} \sin \theta$
- use the formula $\mu_K = \tan \theta$, where θ is the minimum angle at which the cart slides down a slope to calculate the coefficient of sliding friction;
- describe an experiment to measure the normal and parallel components of the weight of an object on an inclined plane.

Notes for the instructor

Learning Objectives for chapter 3

On successful completion of this course, the student will be able to:

- describe two reasons why using a pulley could assist with moving an object;
- explain the meaning of the following terms, relating to pulley systems:
    - mechanical advantage;
    - velocity ratio;
    - energy efficiency;
- describe an experiment to measure the mechanical advantage of a pulley system;
- describe the effect of multiple pulleys on the energy efficiency of the system.

Learning Objectives for chapter 4

On successful completion of this course, the student will be able to:

- explain the meaning of 'snapping' in relation to a toggle mechanism;
- describe an experiment to measure the force needed to make a toggle mechanism 'snap';
- identify three practical applications of toggle mechanisms.

Chapter 1	**Notes**
Worksheet 1 The flywheel Timing 30 - 45 mins	Concepts involved: weight mass gravitational field strength torque equations of motion Newton's second law moment of inertia angular velocity and acceleration equation of a straight line The instructor may need to support the students in processing the results - they involve quite a lot of basic physics! For example, it may be worthwhile pointing out that the equation '$\tau = I \times \alpha$' is simply Newton's second law expressed in terms of angular rotation. Where there are significant differences between the calculated and experimental values for moment of inertia, the instructor could lead a discussion on errors in measurement .

Notes for the instructor

Fundamental MECHANICS

<table>
<tr><th>Chapter 2</th><th>Notes</th></tr>
<tr><td>Worksheet 2
Controlling friction

Timing
80 - 120 mins</td><td>Concepts involved:
static friction sliding friction normal force frictional force
coefficient of static friction coefficient of sliding friction
triangle of forces trigonometric functions

The equipment allows for a wide range of experimentation. A few investigations are given in the worksheets. It is for the instructor to expand on these to meet course requirements.

1. Types of friction:
The practical work requires a very steady hand and a solid bench. Any disturbance is likely to influence the results obtained. Turning the cart upside down is simply a means of comparing the effect of the wheels with that of the metal-metal contact, while keeping the mass of the cart unchanged. The most significant finding is that static friction is greater than sliding friction, an effect that is explored further in the next investigation. For the challenge, it is unlikely that an instructor would want every student to wok through every pair of materials. A more efficient approach assigns specific materials to each group of students. Their results can then be shared across the class later and their practical implications explored.
2. Static and sliding friction:
Once again, the approach is relatively open-ended so that the instructor can adapt it to suit the class. Students obtain sufficient data, for two weights of cart, to allow them to calculate a value for the coefficient of static friction. At this point, the instructor can decide to allocate different materials to different groups of students and, for an able group, to task them with the more detailed investigation, generating a graph of the results.
3. Angle of friction:
As earlier, the practical work requires a very steady hand. The students should be aware that they are investigating sliding friction as they are told to tap the bench to remove static friction effects. Again, depending on the ability and experience of the students, there may be need for considerable instructor support in processing the results.
For the challenge, it is again envisaged that the instructor assigns different materials to different groups of students with results being shared later.</td></tr>
<tr><td>Worksheet 3
Inclined forces

Timing
30 - 50 mins</td><td>Concepts involved:
resolution of forces trigonometric functions

The techniques are similar to those used in the previous investigation. This time, however, the challenge is to measure the normal and parallel components of the weight of the roller. Accuracy depends largely on two factors;
• deciding when the roller is on the point of lifting off the plate;
• keeping the two cords, to the ‘normal’ and ‘parallel’ mass hangers, perpendicular to each other.
The wooden floor can be placed along the long edge of the plate (i.e. parallel to the ‘parallel’ cord,) and used to check that the ‘normal’ cord is perpendicular to it.

This is another good place to initiate a discussion about reading errors.</td></tr>
</table>

Notes for the instructor

Chapter 3	Notes
Worksheet 4 Pulley systems Timing 40 - 60 mins	Concepts involved: load effort work done energy transfer mechanical advantage velocity ratio energy efficiency In the first configuration, there is no force multiplication but that does not mean that the arrangement is of no use. It is sometimes an advantage to change the direction in which the effort is applied. One such case is mentioned in the worksheet, where it helps to be able to use bodyweight as part of the effort. We normally associate the word 'load' with an object that we are trying to lift, and 'effort' as the force we are applying to do so. In these experiments, however, one is a set of weights and the other is provided by a force meter. It is not always obvious which is which! For that reason, the students are asked to unhook the force meter to see how hard they have to pull to move the load. Strictly speaking, the instruction should add "...at steady speed." to the instruction. In the remaining configurations, it is important that the pulleys are strung correctly. One easy check is to count the number of strings between the pulleys, two in this case. The point about energy multiplication may need reinforcement for some. When work is done (by a force moving an object in the direction of the force,) energy is transferred from one form to another, e.g. heat caused by friction. When more work is done by the effort than by the load, the system loses energy and is less than 100% efficient. As later configurations demonstrate, the greater the number of useful pulleys in the system, the greater the mechanical advantage. However, if students watch the hook on the bottom of the force meter, they will see that its movement, the 'distance moved by the effort', is greater than the distance the load moves. A more detailed study would show that the losses due to friction increase too.

Notes for the instructor

Chapter 4	Notes
Worksheet 5 The toggle mechanism Timing 30 - 50 mins	Concepts involved: toggle mechanism It may not appear obvious from the apparatus setup just what a toggle mechanism is. For that reason, the worksheet has a simplified diagram, illustrating the principle. Essentially, there are two applied forces, one horizontal, the load, provided by the spring, the other vertical, provided by the effort. An integral part of its behaviour is the 'snapping' to its ultimate locked position. Students observe this at the outset by pressing down gently on the mechanism. The instructor could discuss the action of a 'toggle' switch, in electrical circuits at this point. Allow plenty of time for the students to set up the apparatus. A 'fine-tuned' setup will make the experiment much easier and more reliable. It is critical that the adjustable pulley is tightly fastened in place as, should it move, all the readings will be affected. Equally important is the gentle tapping needed before the force meter reading is taken, to overcome the static friction between the roller wheels and the toggle roller plate. The shape of the graph may not be immediately obvious for low values of effort. Higher values indicate that the relationship is not linear, but suggest an upward turning curve. The instructor could ask students to interpret this shape in terms of the effort and load. The picture of a car screw jack illustrates one application of this mechanism. Again, it could be the starting point for a discussion on ways in which this mechanism proves useful.