

# White Knuckle Ride (Experimental)

## An Introduction to Dynamics

This version of the problem has been adapted to be an experimental introduction to dynamics.

### Intended Learning Outcomes

By the end of this activity students should be able to:

- Distinguish between static, kinetic and rolling friction
- Set up and analyse equations of motion in linear and circular motion, using approximations where appropriate
- Use kinetic and potential energies
- Calculate work done through friction

Students will use the following skills:

- Designing of experiments to test a hypothesis
- Evaluating the errors in an experiment and their consequences
- Working as a team
- Report writing

#### KEYWORDS:

Dynamics, static friction, kinetic friction, rolling friction, equations of motion, linear motion, circular motion, kinetic energy, potential energy, work done.

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The original form of this problem is an experimental Group Research Project on the Physics degree course at the University of Leicester. Students are organised into small groups working as teams. Most, if not all, of the required theory can be found in standard first year physics texts.

## Reading List

The following textbooks are suggestions, other equivalent textbooks are available:

- Breithaupt, J. **Physics**. Palgrave Foundations.
- Tipler, P.A. **Physics for Scientists and Engineers**. Freeman.



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## Problem Statement

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### Memo 1:

#### Chyphsis Toys Ltd

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Our marketing department see a niche for a gravity powered roller-coaster toy of some sort: nothing too complicated – just a straight track for example. In order to convince potential investors we need some good calculations as to what can be done. We've had some prototypes of the cart put together, but I don't want to bend any tracks until after I've seen your report and we've some idea of what would work. What are the sources of friction? What heights do you think we can use for successive humps? How many humps should we have? I don't think the friction on these rails is particularly low; would it be better if we used a Teflon coating? Would your results scale if we were to decide to produce a suite of toys? At this stage I'm not interested in cosmetic aspects – we'll get the design guys to deal with that.

I'll need a formal report from you with your results.

*Roberta*

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### Memo 2:

I've had a contact from Chyphsis Toys about a roller coaster toy. Take a look at it please. I think we need to put in some basic work on this one. I've sorted out some tracks and carts and some basic equipment you might need. I'd like an initial report on the following:

The static friction on these toys – this should give an upper limit to what we've got here.

The sliding friction – so we can compare with rolling friction

The rolling friction – this is the one that counts

Once we've got these we'll think about the design

*Director of Research*

## Suggested Deliverable

Individual or Group reports to the director of research.

## Laboratory Equipment Provided

1 x Metre Rule	1 x Stop Clock
2 x IR Light Gates	1 x Bread Board
2 x Male-Male Connecting Wires	4 x Male-Croc Clip Connecting Wires
1 x Role Spare Wire	2 x Male-Coaxial Adaptors
1 x PC Data Logger	1 x Power Pack
1 x Tool Kit (inc Wire Strippers)	1 x 500x500mm Black Card
5 x 200gram Masses	1 x Light gate information sheet
4 x Boss, retort and clamp set	1 x Multi-meter
1 x Pair Scissors	1 x Role Selotape
1 x Role Duct Tape	1 x Pack Blu-Tac
1 x Marker Pen	1 x Weighing Scales

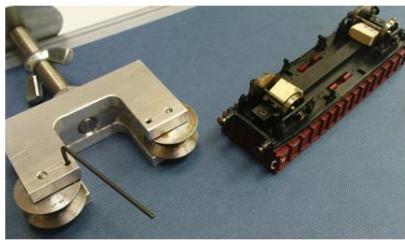
Groups should also have one of the following sets of equipment:

### Train-track group:

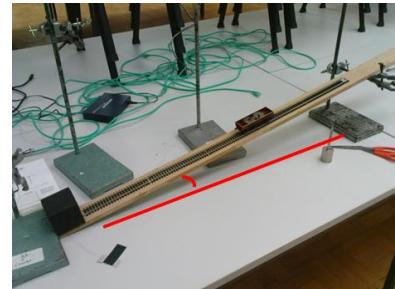
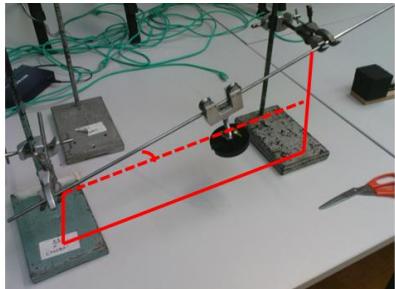
1 x Model Cart	2 x Train Track (~700mm length)
1 x Train Track (~160mm, fixed to MDF board)	1 x Plywood Board (100x1400mm)
1 x Buffer	6 x Small Clamps
2 x Large Clamps	2 x Wooden Axle Wedges

### Monorail Group:

1 x Monorail Cart	1 x Straight Metal Rod (~1200mm length)
1 x Curved Metal Rod (~1200mm length)	3 x Small Clamps
1 x Cleaning pad	



Overhead rail and train



## Laboratory Sessions

### Session 1: Static Friction Experiment

#### Locate the Problem

- Devise a method for measuring the coefficient of static friction
- Examine the weight dependence of static friction.

#### Learning Issues

You will have to consider both the force acting on the train, and the force of friction at a given angle. To do this you must take components of each of these forces along the direction of travel.

#### Locate the problem

Measure the coefficient of kinetic friction of the same equipment you used in the previous lab session.

### Session 2: Kinetic Friction Experiment

#### Locate the problem

Measure the coefficient of kinetic friction of the same equipment you used in the previous lab session.

#### Learning Issues

Four different methods have been suggested to you:

1. Use constant acceleration formulae with measured time (Eqn of motion)
2. Use constant acceleration formulae with measured velocity (Eqn of motion)
3. Measure work done
4. Measure acceleration directly

You are also free to choose a different approach.

Which one of these you choose depends on the errors and difficulties associated with each one. You should consider this before making your choice or make a comparison if time allows.

## Session 3: Rolling Friction Experiment

### Locate the problem

Does rolling friction depend on velocity (and if so, how)?

Form of friction suggested to you:

$$F_f = -mr\nu$$

where:  $r$  = coefficient of rolling friction

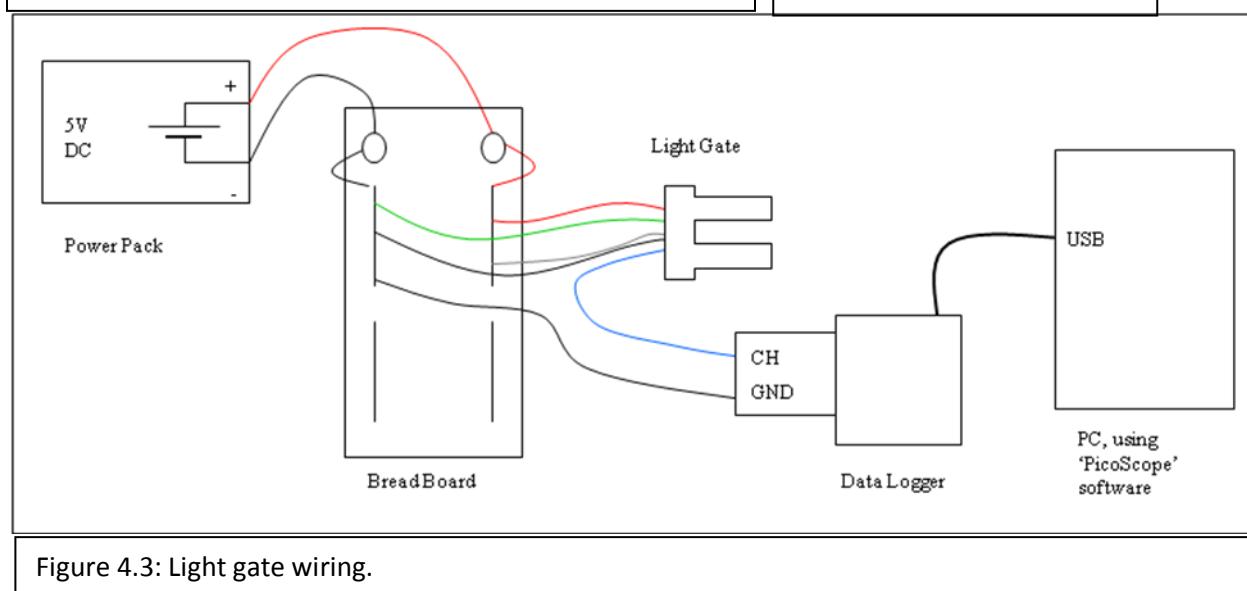
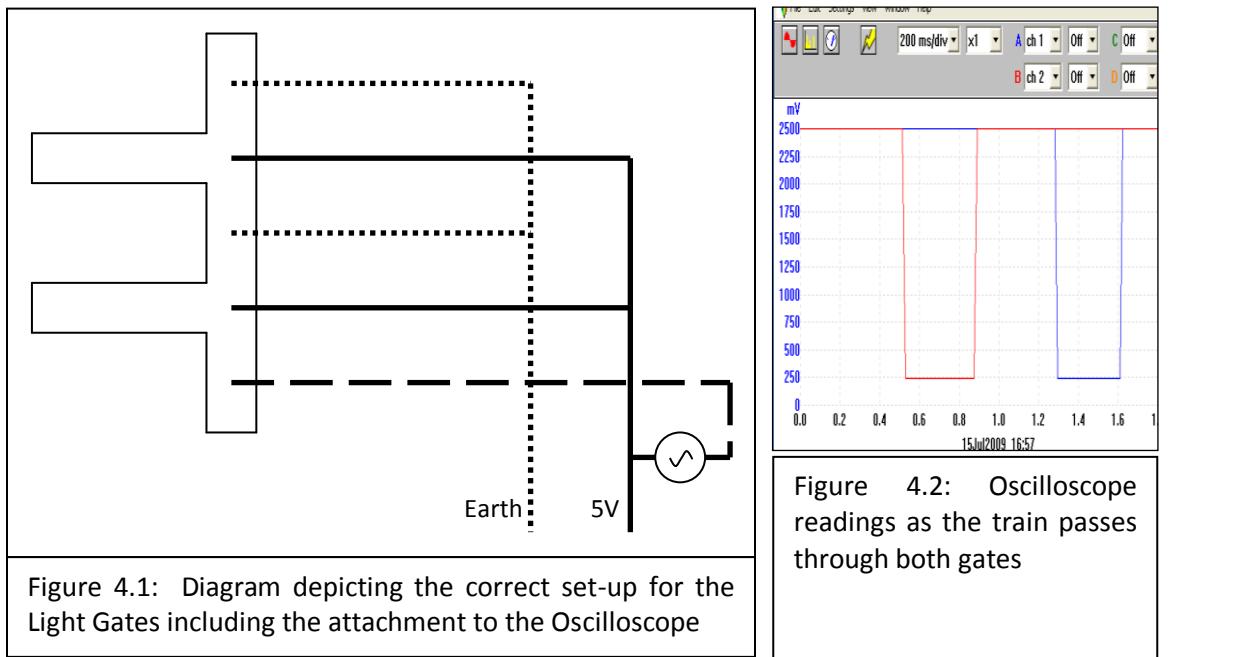
### Learning Issues

How do you measure departures from constant acceleration? You might find it useful to think of several ways before making a decision!

## Supplementary Information

### Light Gates

When properly connected to the Oscilloscope and a Power Supply the Light Gates will produce an output equivalent to the input voltage that will be displayed on the oscilloscope as an unwavering line at or around that voltage. As a trigger passes between the prongs of the gate the voltage will drop to zero until the trigger is removed. The time the trigger is within the gate will be displayed on the oscilloscope as a square trough. The accuracy of the gate is enough so that the accuracy of the Oscilloscope determines the accuracy of the results.



If too high a voltage is applied to the light gates, they can be damaged. As they work with only a few volts put across them there should be no reason for this to happen.

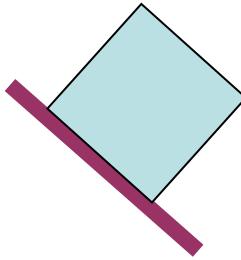
## Oscilloscope Information

It is recommended that the students use the 'Pico ADC-11' data logger in conjunction with the light gates. This is used through the 'PicoScope' software. The output from each light gate (blue wire) is to be connected individually to different channels (e.g. CH1 and CH2). Then the two channels can be selected in 'PicoScope' (at the top right).

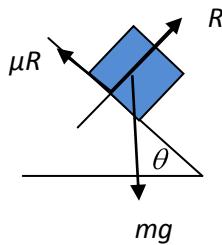
- The ground of the data-logger (labelled GND) also must be connected (the negative bus on the breadboard would be suitable).
- The time per divide must be set to be at least 200ms. As this gives the best resolution, this setting is recommended.

## Questions for Class Discussion

1. Does the box tumble or slide? List the assumptions you make.



2. If the frictional force is assumed to be independent of velocity show that the effective acceleration of a block on a plane inclined at an angle  $\theta$  to the horizontal with coefficient of friction  $\mu$  is  $g(\sin \theta - \mu \cos \theta)$ .



3. (a) Show that the equation of motion for the speed  $v$  of a body of mass  $m$  rolling down a plane inclined at angle  $\theta$  to the horizontal under a frictional force of the form  $F_{\text{fric}} = -mr v$  with  $r$  a constant is

$$\frac{dv}{dt} + rv = g \sin \theta \quad (1)$$

(b) Confirm (by substitution in (1) or otherwise) that a solution of the equation is

$$v = \frac{g \sin \theta}{r} \left( -e^{-rt} \right)$$

(c) By expanding the exponential as a power series show that

$$v \approx g \sin \theta (t - rt^2/2)$$

to first order in  $r$ , and hence, by integrating, that the distance traveled down the slope in time  $t$  is approximately

$$s = \frac{g't^2}{2} - \frac{rg't^3}{6}$$

where  $g' = g \sin \theta$ .

(d) Verify (by substitution for  $v$  or otherwise) that to this order

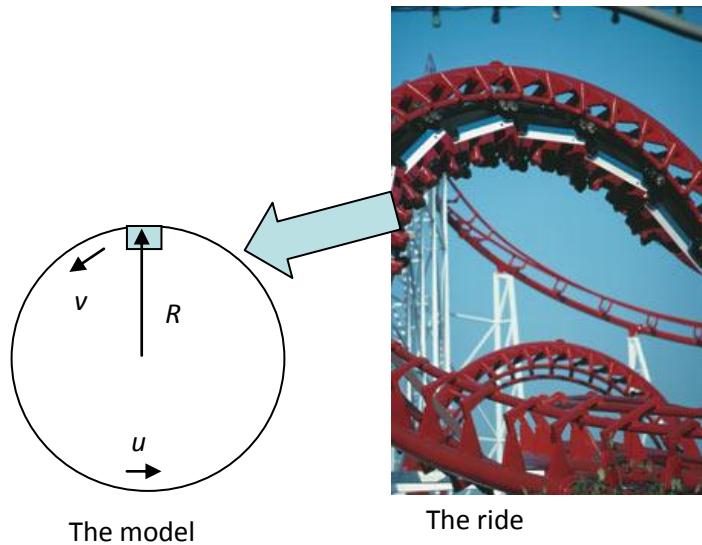
$$s \approx \frac{v^2}{2g'} + \frac{rv^3}{3g'^2}$$

(e) How could you use the results in (c) and (d) to investigate the applicability of this form for the friction in your experiments?

4. Show that the work done by rolling friction of the form  $F_{\text{fric}} = -mr\dot{v}$  from rest to a speed  $v$  is

$$\frac{mr\dot{v}^3}{3g'}$$

5. Assuming that the carts are not attached to the rails, does the g-force on the riders limit the diameter of a circular track in a fairground ride?



6. What effect would a teflon coating have on the design of the toy track for **Chysis**?

7. Can you scale the model (up or down i.e. multiply all lengths by a constant factor, all masses by a factor and so on)? To answer this, show that if the frictional force is  $rv$ , independent of mass, with  $r$  a constant then (to first order in  $r$ ) the ratio of successive heights  $h_2/h_1$  is

$$\frac{h_1 - \frac{r}{3gg'm} (2gh_1)^{3/2}}{h_1}.$$

Show that this is independent of the scale provided that the mass of the cart is proportional to  $h_1^{1/2}$ . [Hint: consider the work done and use question 4 ]

Can the ride be scaled at all if the friction is  $mr\dot{v}$ ? Is air resistance important in full scale rides?