University of Leicester

National HE STEM Programme Physics

WHITE KNUCKLE EXPERIMENT

FRICTIONAL FORCES - LABORATORY INVESTIGATION

The Centre for Interdisciplinary Science

CETL Physics Innovations
Centre for Excellence in Teaching & Learning

PREAMBLE

The original form of the problem is an Experimental Group Research Project, undertaken by students organised into small groups working as teams. Most, if not all, of the required theory can be found in standard first year physics texts

MODULE PACING

The module is run with the following pattern over 3 weeks

Introduction (1 hour)

Facilitated Practical Class (2 hours)

Facilitated workshop – problems for class discussion (1.5 hours)

Facilitated Practical Class (3 hours)

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Facilitated workshop – problems for class discussion (1.5 hours)

Facilitated Practical Class (3 hours)

INTENDED LEARNING OUTCOMES

By the end of the module students should be able to:

- Distinguish static, kinetic and rolling friction
- Write down and solve equations of motion
- Solve problems using kinetic and potential energies
- Evaluate the 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

READING LIST

The reading list is that provided for the original module. Other equivalent textbooks are available.

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

SUGGESTED DELIVERABLES

Individual or group reports to the director of research

LABORATORY EQUIPMENT PROVIDED

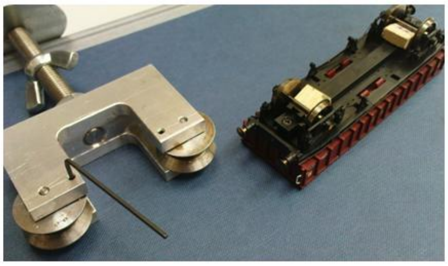
1 x Metre Rule
2 x IR Light Gates
2 x Male-Male Connecting Wires
1 x Role Spare Wire
1 x PC Data Logger
1 x Tool Kit (inc Wire Strippers)
5 x 200gram Masses
4 x Boss, retort and clamp set
1 x Pair Scissors
1 x Role Duct Tape
1 x Marker Pen

1 x Stop Clock
1 x Bread Board
4 x Male-Croc Clip Connecting Wires
2 x Male-Coaxial Adaptors
1 x Power Pack
1 x 500x500mm Black Card
1 x Light gate information sheet
1 x Multi-meter
1 x Role Selotape
1 x Pack Blu-Tac
1 x Weighing Scales

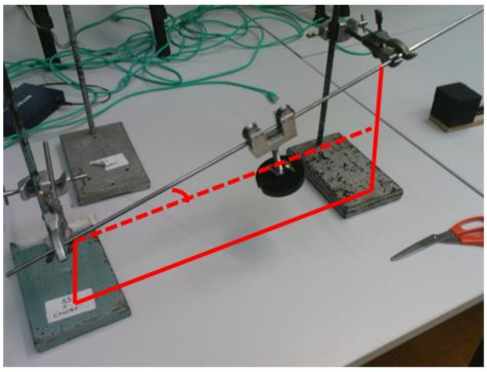
Groups should also have one of the following sets of equipment:

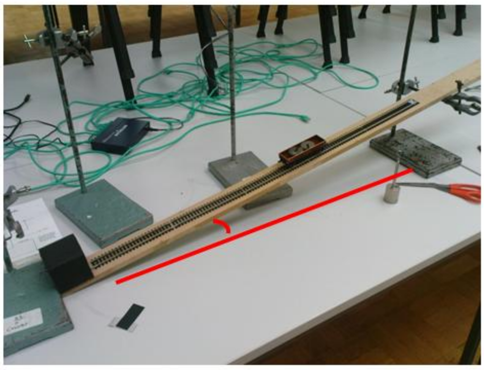
Train-track group:
1 x Model Cart
1 x Train Track (~160mm, fixed to MDF board)
1 x Buffer
2 x Large Clamps
2 x Train Track (~700mm length)
1 x Plywood Board (100x1400mm)
6 x Small Clamps
2 x Wooden Axle Wedges

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



Overhead rail and train





PROBLEM STATEMENTS

Memo 1:

Chypsis Toys Ltd

Our marketing department see a niche for a 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 laboratory data and calculations as to what can be done. We want it to be gravity powered, but haven't decided whether it should be on a monorail or train track. 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. Your team will be working on either the monorail or dual track system. 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

Memo 2:

Project Brief

I've had a contact from Chypsis 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

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.

LAB 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 (Eq^n of motion)
2. Use constant acceleration formulae with measured velocity (Eq^n 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. .

LAB SESSION 3: ROLLING FRICTION EXPERIMENT

Locate the problem

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

Form of friction suggested to you:

$$F_f = -mrv$$

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.

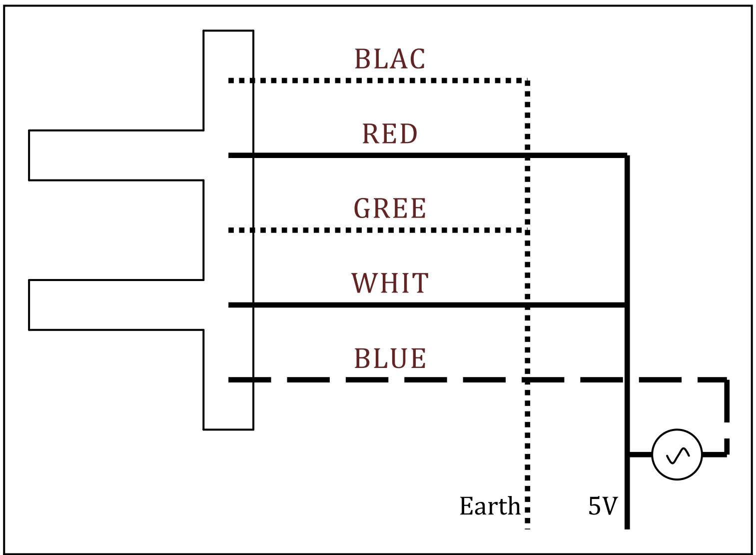


Figure 4.1: Diagram depicting the correct set-up for the Light Gates including the attachment to the Oscilloscope

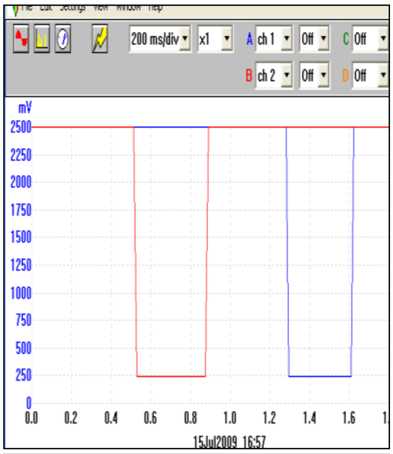


Figure 4.2: Oscilloscope readings as the train passes through both gates

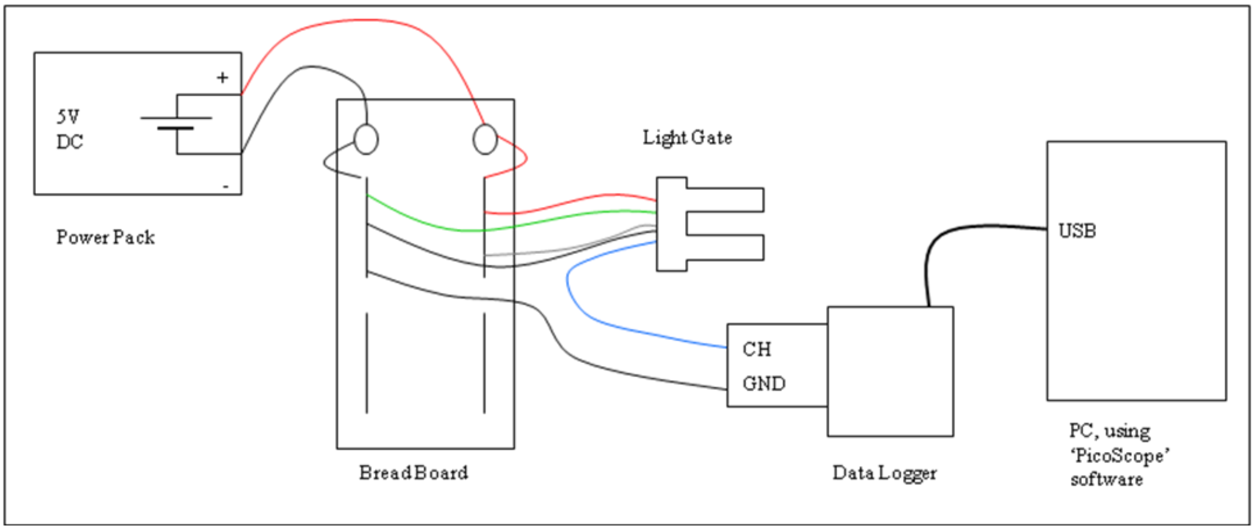


Figure 4.3: Light gate wiring.

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.

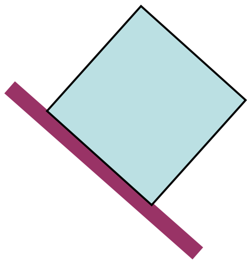
OSCILLOSCOPE INFORMATION

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).

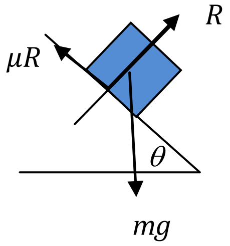
- The ground of the data-logger (labelled GND) also must be connected (the negative bus on the breadboard would be suitable).
- The time per divide must be set to be at least 200ms. As this gives the best resolution, this setting is recommended.

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 θ to the horizontal with coefficient of friction μ 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 θ to the horizontal under a frictional force of the form $F_{fric} = -mrv$ with *r* a constant is

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

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

$$v = \frac{g\sin\theta}{r}\left(1 - e^{-rt}\right)$$

(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

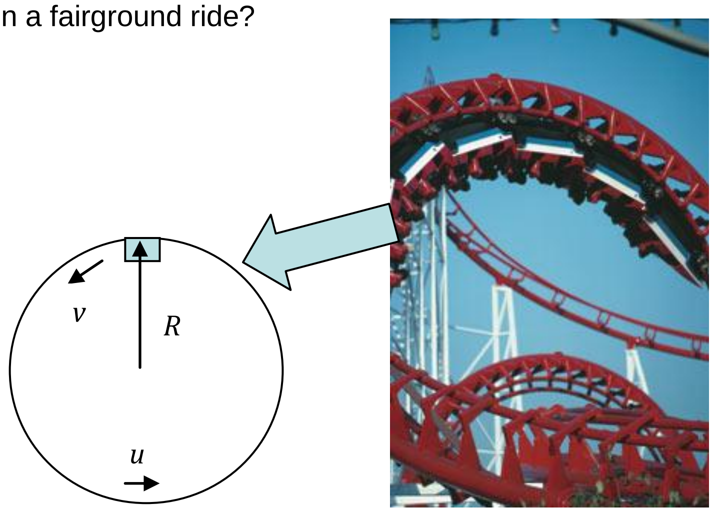
$$s \approx \frac{v^2}{2g'} + \frac{rv^3}{3g'^2}$$

(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 $F_{fric} = -mrv$ from rest to a speed v is

$$\frac{mrv^3}{3g'}$$

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?



The model   The ride

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

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 mrv? Is air resistance important in full scale rides?