Raspberry Pi Powered Gravity Experiment

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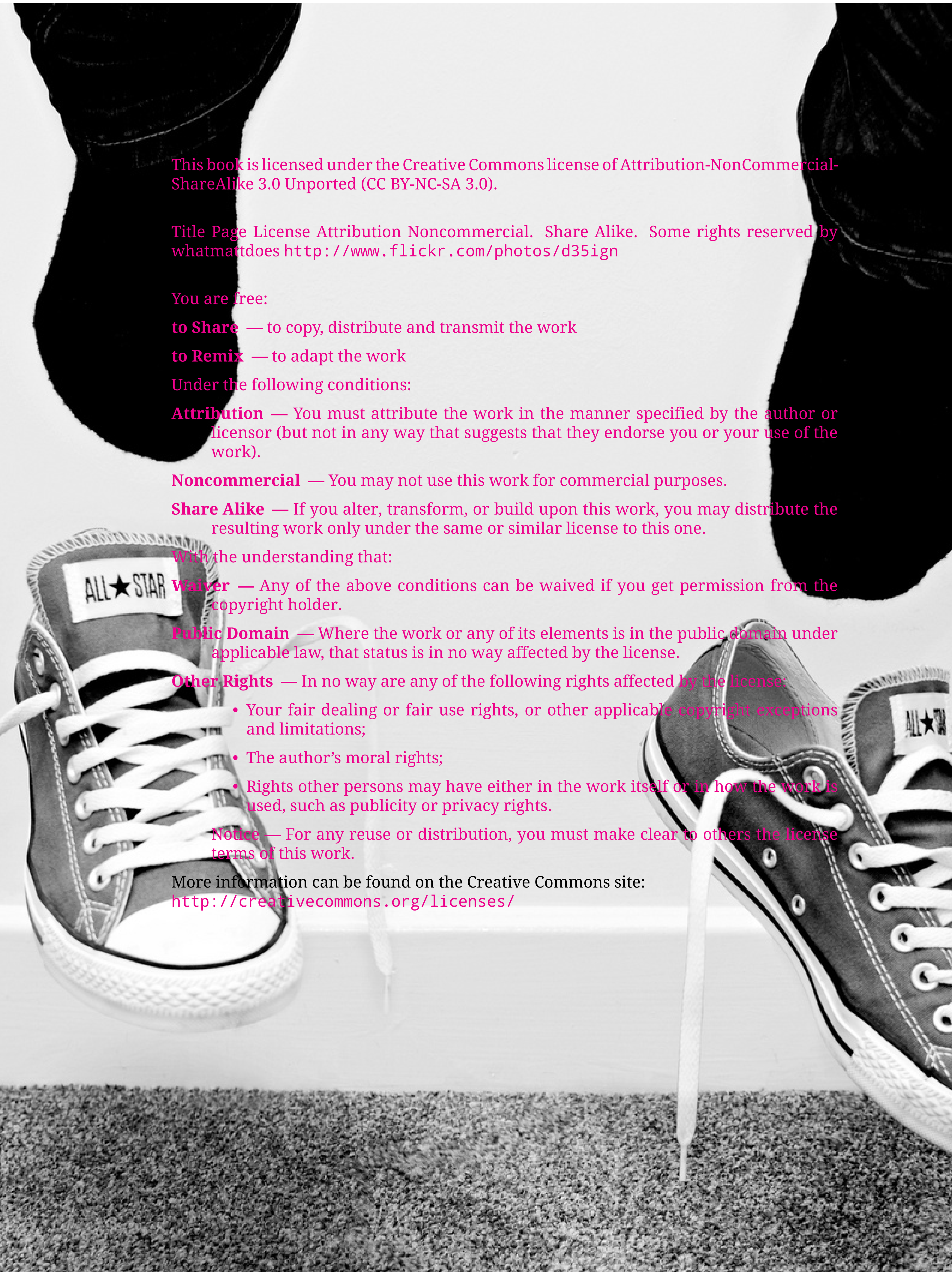
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Chapter 1

The STEM Network Ogden Trust Challenge

1.1 Raspberry Pi Gravitational challenge sponsors

Chapter 2

Raspberry Pi

2.1 Background

The Raspberry Pi (Figure 2.1) is a credit-card sized computer that plugs into your TV and a keyboard. It is a capable little computer which can be used in electronics projects, and for many of the things that your desktop PC does, like spreadsheets, word-processing and games. It also plays high-definition video.

It costs about £31 including an SD Card, but without a keyboard, mouse, monitor, and cables.

It uses a standard smartphone charger to get power. It has two USB sockets, a network port and an HDMI socket for attaching to a monitor or TV.

2.2 Using a Raspberry Pi in an experiment

This experiment uses the Raspberry Pi to control an electromagnet and to act as a highly accurate stopwatch. The Pi drops a ball bearing from an electromagnet and measures exactly how long after release it takes to land. To control an electromagnet without endangering the Pi, it is useful to use a Raspberry Pi expansion board such as the PiFace.

2.3 Raspberry PiFace

A PiFace Digital is an expansion board for the Raspberry Pi (Figure 2.2). It plugs into the GPIO (General Purpose Input Output pins) of a Raspberry Pi, allowing you to sense and control different electric and electronic objects.

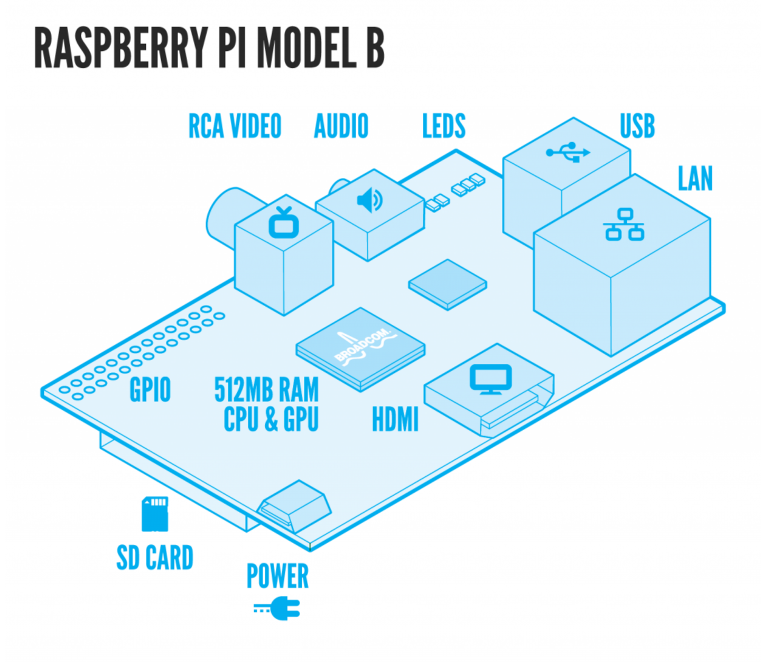

Figure 2.1: Raspberry Pi connections.

With PiFace Digital you can detect the state of a switch, for example from a door sensor or a pressure pad. Once a change in state has been detected, the Raspberry Pi can determine how to respond. The PiFace allows the Raspberry Pi to respond by powering motors, solenoids, bells etc.

In this experiment, the Raspberry Pi is going to send a command to the PiFace to switch on/off an Electromagnet. This will cause a ball bearing to fall from the attached electromagnet. The Raspberry Pi will then detect a switch being closed when the ball bearing lands.

There are two methods of detecting when the ball bearing lands:

- Getting a person to push a switch when they see the ball bearing land.
- Building a pressure plate switch which will close when the ball bearing presses the plates together.

Q: Which method is better? Why?

The experimenters will be making the pressure plate switch which detects when a ball bearing lands When the ball bearing hits one piece of foil, it crashes into another piece of foil and the circuit is complete. The Raspberry Pi runs a program listening for the circuit to complete.

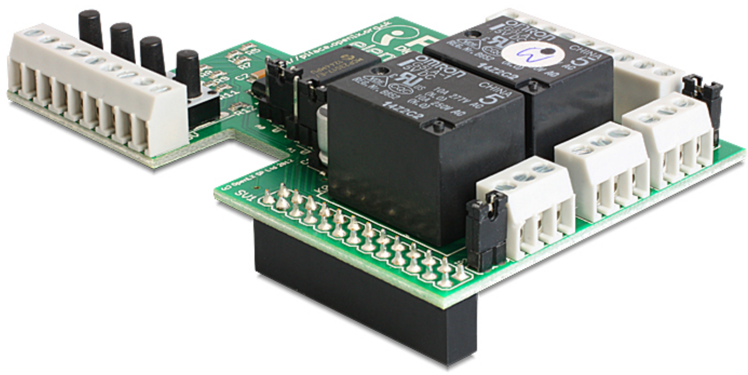

Figure 2.2: PiFace digital connections. Image taken from http://www.dlbilder.de/produkte/orig/513d9f110168c0.17822864.jpg. The GPIO pins are in the front of this image (2x13 connector). Look for 26 little solder tepees.

2.4 Building a pressure plate switch

2.4.1 Materials Required

- Aluminium Foil.
- Scissors.
- 2 × Bendy Straw.
- 2 × 2m wire.
- 2 × blob of Blu-tack rolled into balls,
- Sellotape to stick the wires to the Aluminium foil.

2.4.2 Instructions

Bend the bendy straws so that they form a right angle. Form the two straws into a rectangle by pushing them into the Blu-tack (Figure 2.3).

- Cut two pieces of Aluminium foil to the same size as your straw rectangle.
- Ensure that the aluminium is nice and flat.

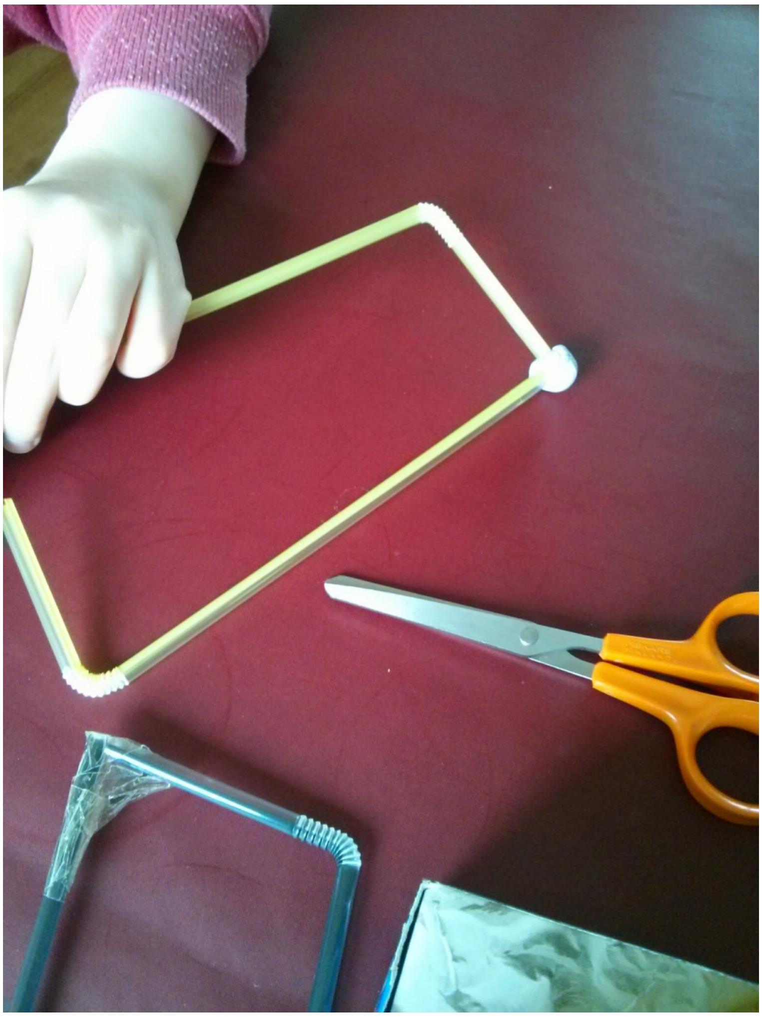

Figure 2.3: Create the frame for the pressure plate switch, by connecting two straws together with Blu-Tack. The straws act as an insulator between the two conducting layers of aluminium.

- Lay one piece on the bottom of the straws (Figure 2.4) and attach one wire to it using sellotape.
- Examine the wires. **Note that the wire is not the same at both ends. We want to use the end of the wire which has the most copper exposed**.
- Attach the other wire to the top piece (Figure 2.5) using sellotape. Place the top plate onto the Blu-Tack ensuring that the two plates are not touching.
- The tinfoil switch is almost complete (Figure 2.6). Using the small screwdriver, attach the switch to your PiFace (Figure 2.7).

Line the switch up underneath the flat end of the electromagnet. **Measure the distance** in metres between the bottom of the electromagnet and the pressure plate switch. This

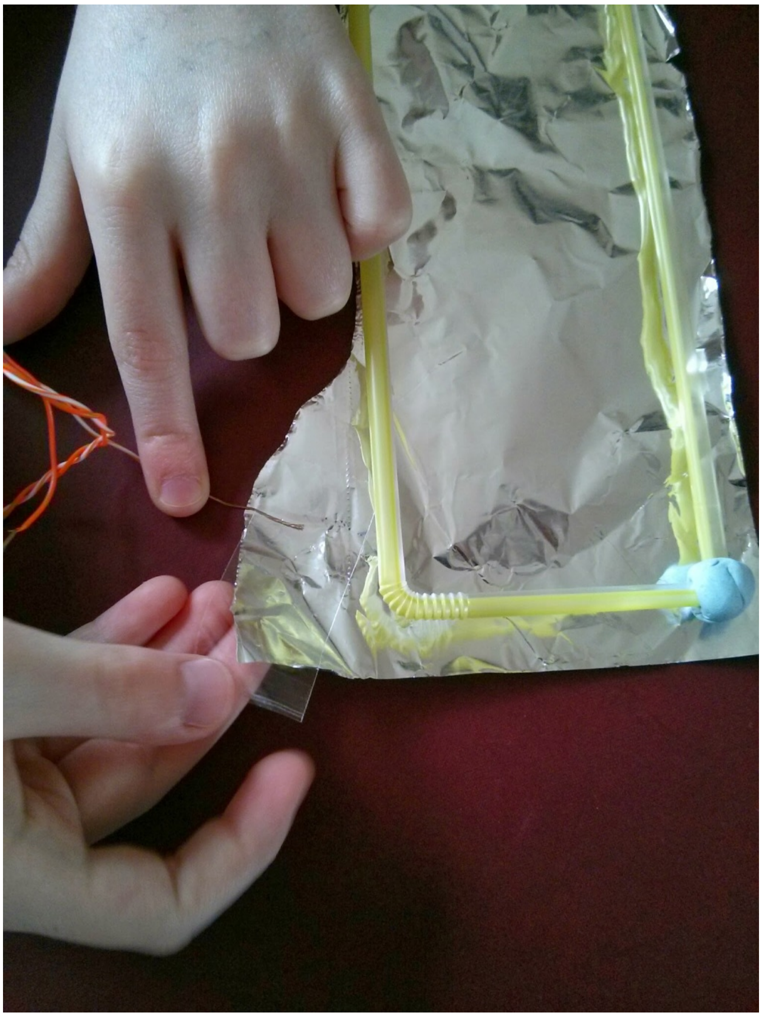

Figure 2.4: Attach a wire to the bottom piece of aluminium. Note this end of the wire has lots of copper exposed.

value is the height variable which must be edited into the Python program.

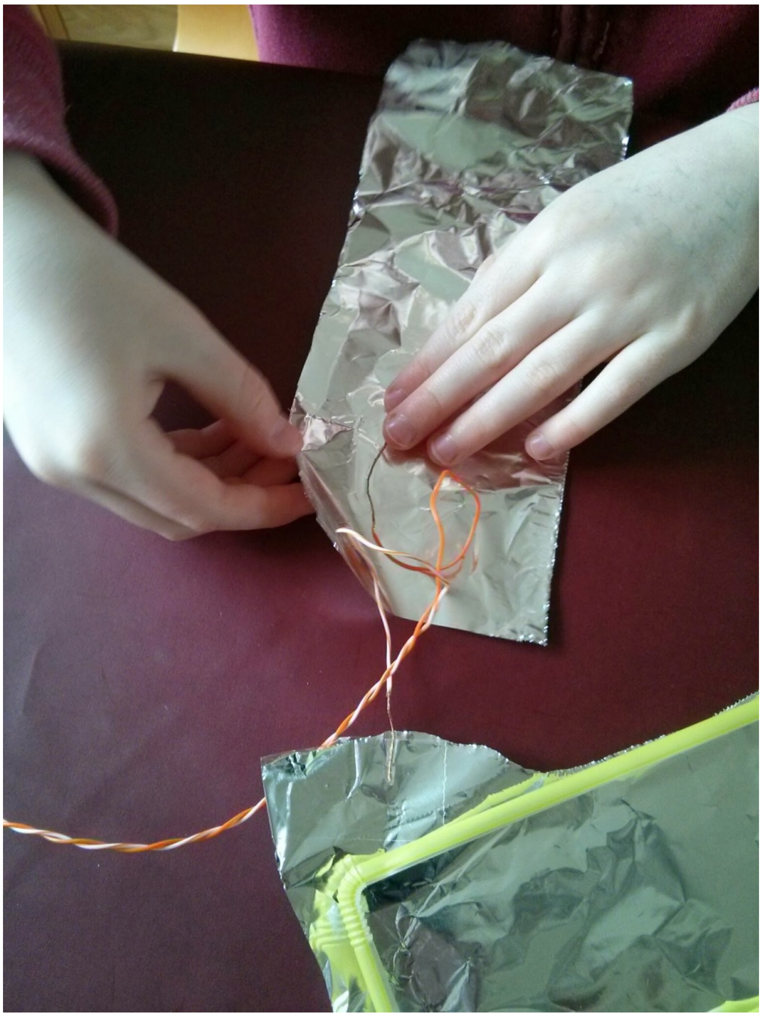

Figure 2.5: Attach a wire to the top piece of aluminium.

Figure 2.6: Tinfoil switch complete.

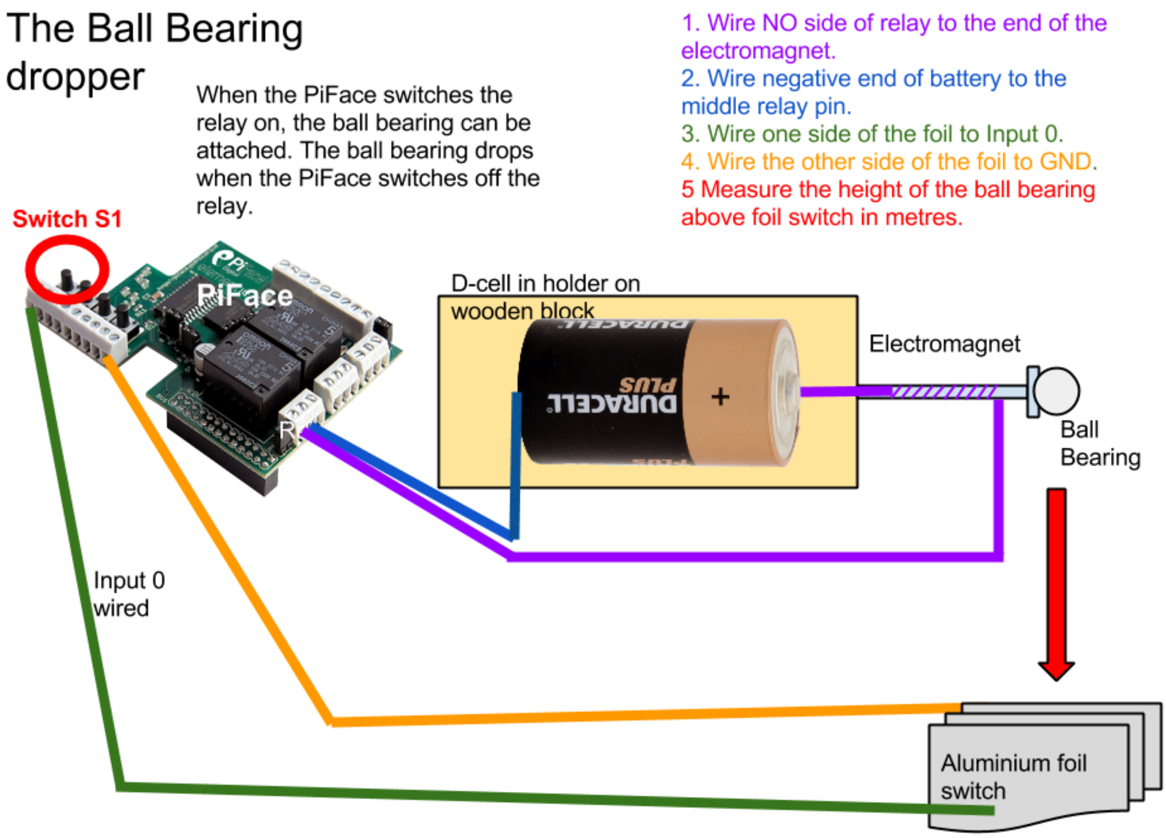

Figure 2.7: Electromagnet wiring diagram for the PiFace.

Chapter 3

Python programming

3.1 Editing and running a Python program

To edit the Programs which will run the experiment on the Pi, we will use a language called Python. Python is fairly simple to use, but incredibly powerful. For editing and running Python during the experiment, use the IDLE program (IDLE stands for **I**ntegrated **D**eve**L**opment **E**nvironment) . Double click on the IDLE Icon on the desktop (Figure 3.1).

Open the gravity.py file using File→Open→Desktop→Gravity→gravity.py (Figure 3.2).

Before running, it is often a good idea to review the code before running it to check that it works as planned.

Edit the height *variable* at the top of the program. A variable is a value in a computer program which can change. For this experiment, the variable will not change, but is used to improve the clarity of the computer program. Figure 3.3 shows the location of **height** = **0.70** . Edit this to the appropriate height for the electromagnet from the pressure plate switch.

3.2 Running a Python program

Using the top menu, click on Run− >Run Module (Figure 3.3).

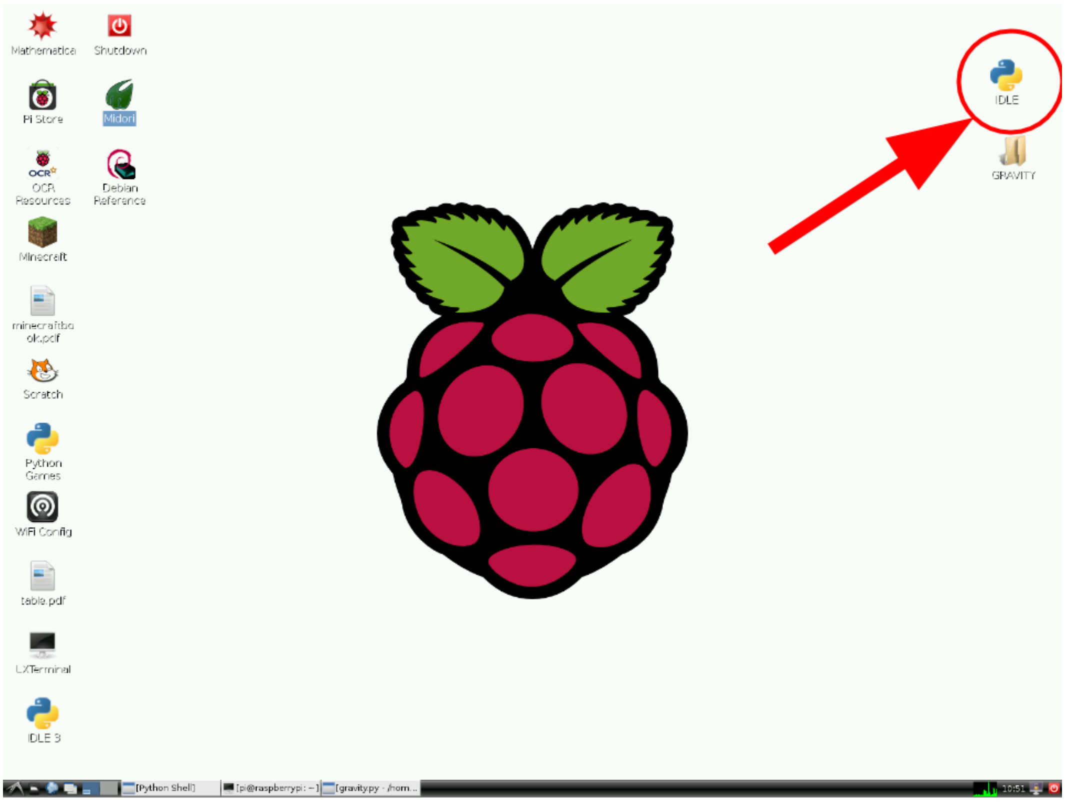

Figure 3.1: Starting IDLE

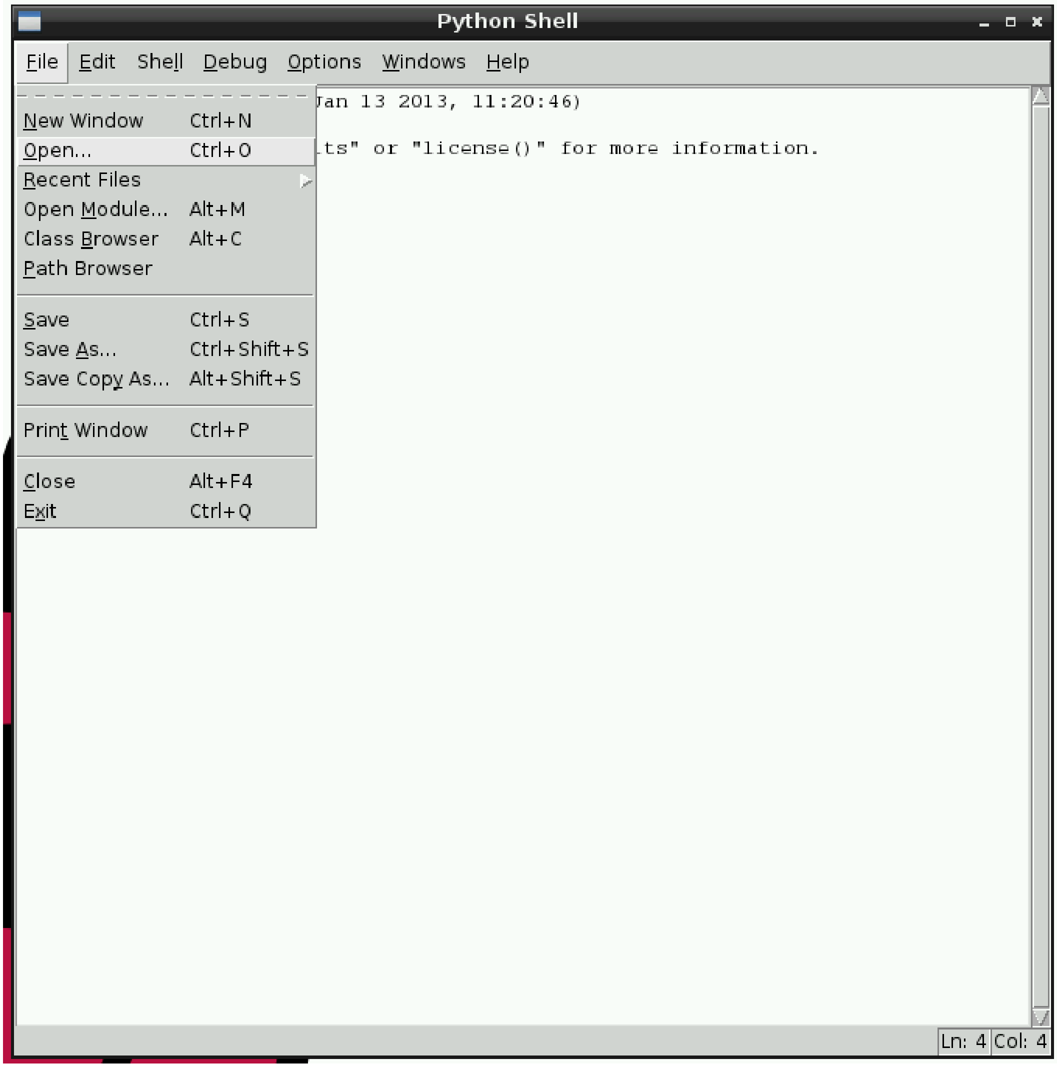

Figure 3.2: Opening files using IDLE

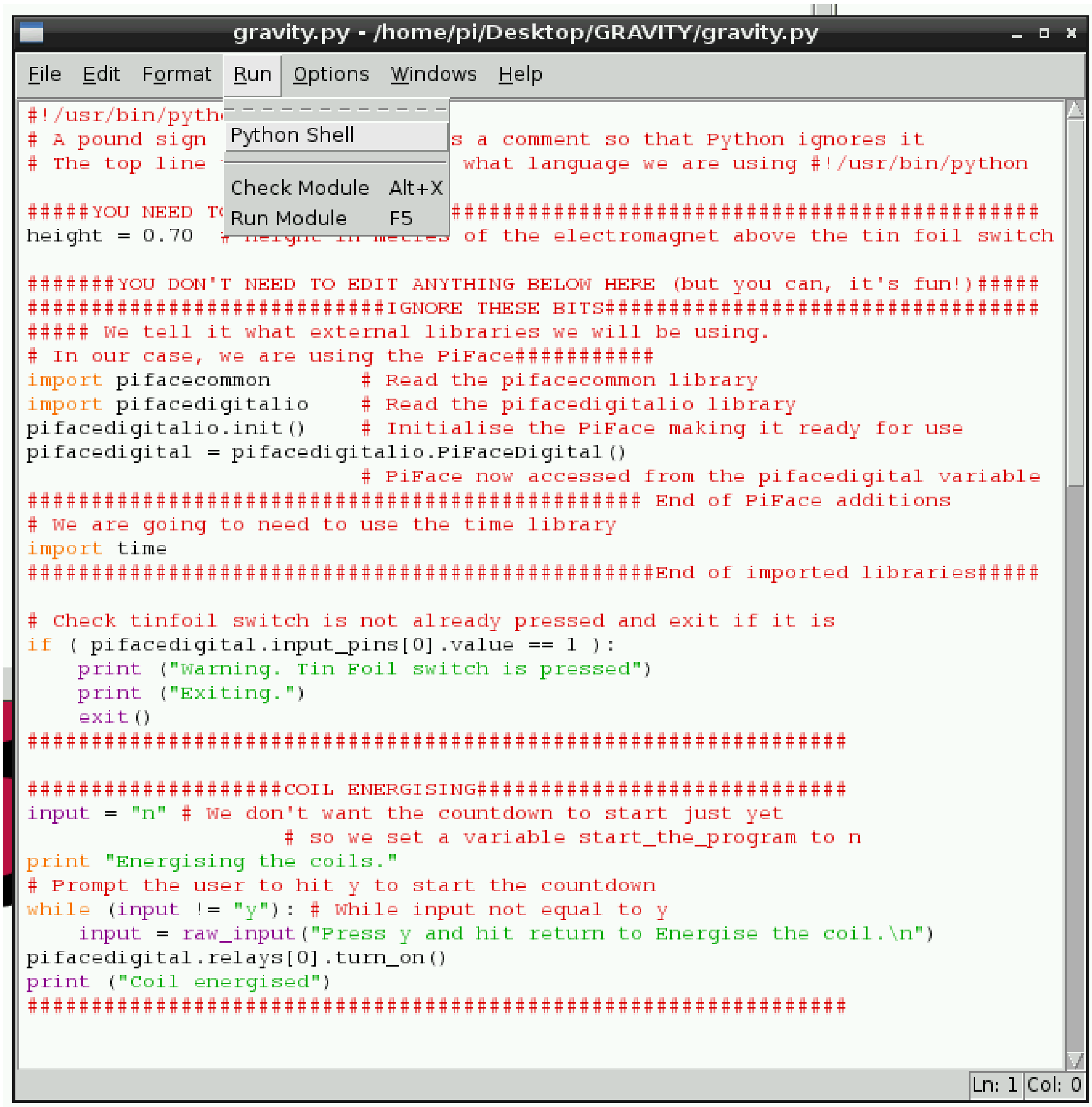

Figure 3.3: Running a program under IDLE. In this screenshot it is the bottom option which should be run (F5).

Chapter 4

Electromagnets

4.1 Introduction

When a electrons flow through a conductor, they cause a magnetic field to be created. An electron flow is known as a **current**. When the electrons stop flowing the magnetic field disappears. If we loop the wire into coils, we can create an **electromagnet**, which only operates when the current is flowing. An iron core can be placed in the middle of the loop of wires. This concentrates the magnetic field, making it even more powerful. The more loops we can wrap around the iron core, the more powerful the electromagnet.

4.2 Making an Electromagnet

To make the electromagnet, hammer an iron nail into a piece of wood. Wrap insulated thin copper wire around the iron nail with all loops in the same direction (clockwise or anticlockwise, but not both). Pass a current through the wire - for this experiment a size D cell (battery) will be used. These provide plenty of current for many repetitions of the experiment.

The electromagnet is controlled by switching on and off the current flow. In this experiment this is achieved using a Relay. This allows small electronic devices to control bigger electrical devices such as Motors, Electromagnets, High Voltage equipment and Solenoids. **The Relays we are using, Motors and Solenoids all use work using the principles of Electromagnetism. We are using Electromagnets to control other Electromagnets!** In this experiment the relay used is controlled via an electronic board called a PiFace which is an add on-board for the Raspberry Pi.

When the current is flowing through the circuit (relay closed), a ball bearing can be attached to the electromagnet (Figure 4.1). When the current stops flowing the ball bearing will drop.

Q: A relay has a Normally Open connection and a Normally Closed connection. We are going to use the Normally Open connection which will mean the Electromagnet will only work when the Relay is on. What would happen if the electromagnet was wired to the Normally closed side of the Relay?

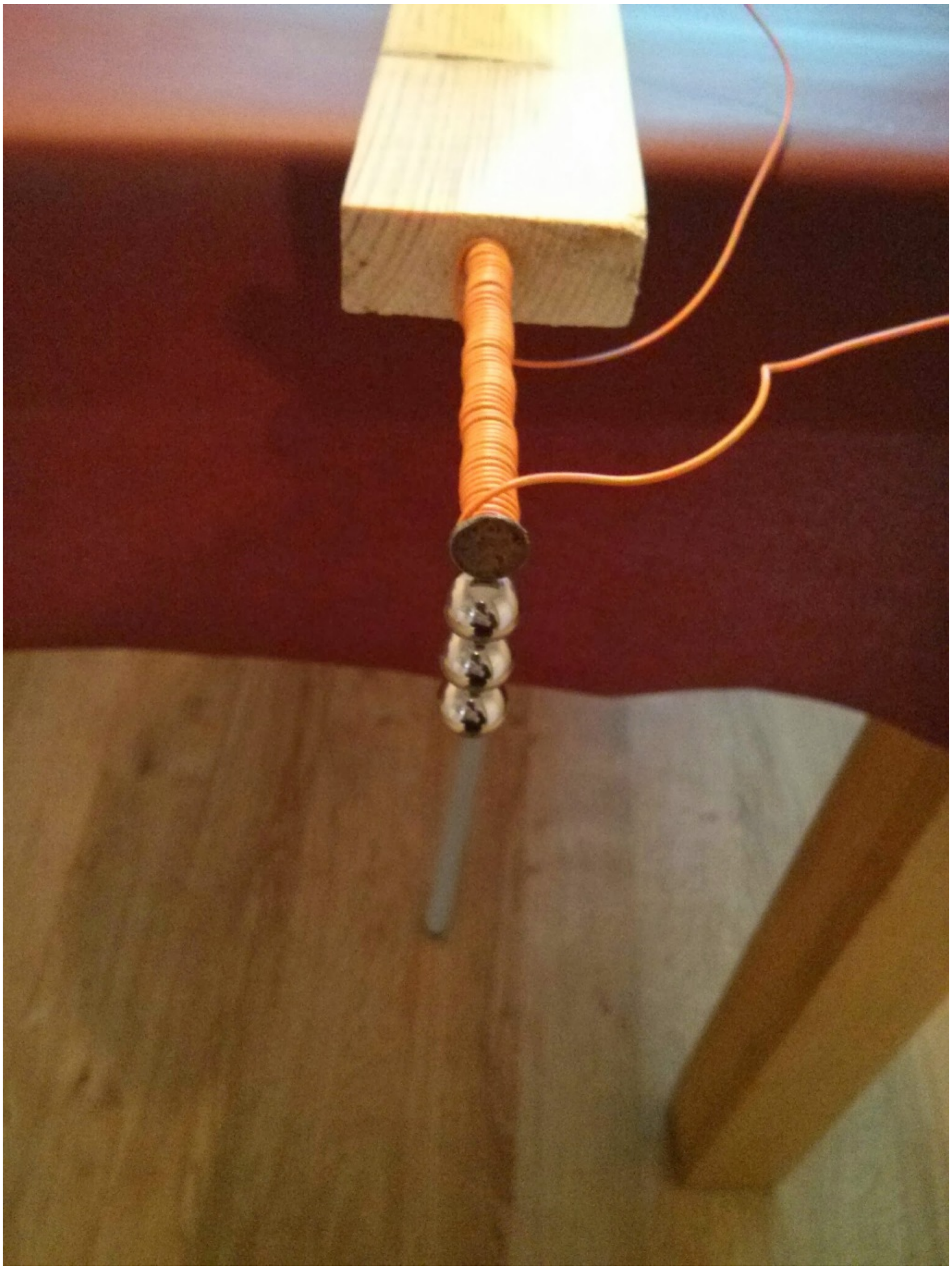

Figure 4.1: Electromagnet made from a nail wrapped in wire. A 1.5V D-cell battery supplies this electromagnet

Sometimes when the electromagnet is switched off, it does not fully demagnetise. This is called residual magnetism. In this experiment, we aren't going to worry about this too much. If the magnet keeps hold of one or more ball bearings, we'll just stick more on! Ask a helper if you are unsure.

4.3 Uses of Electromagnets

Electromagnets are used in Recycling centres to sort the Iron from other metals.

Incredibly powerful Electromagnets can be made, such as those found in MRI scanners (Figure 4.2). These are so powerful, they can "spin" protons inside the atoms in your body! Looking at how the spin changes as the magnetic field is changed allows doctors and clinicians to image all parts of your body without the need for surgery or X-rays.

Figure 4.2: Philips MRI in Sahlgrenska Universitetsjukhuset, Gothenburg, Sweden. Copyright: Jan Ainali 2008

Electromagnets are also incredibly useful to steer charged particles (ions, protons, electrons or more exotic particles). The Rutherford Appleton Laboratory in Oxford use very large electromagnets in their Synchrotron radiation source, as do scientists and engineers working at CERN in France/Switzerland. The magnets at CERN generate powerful 8.4 tesla fields - 100,000 times more powerful than the Earth's magnetic field.

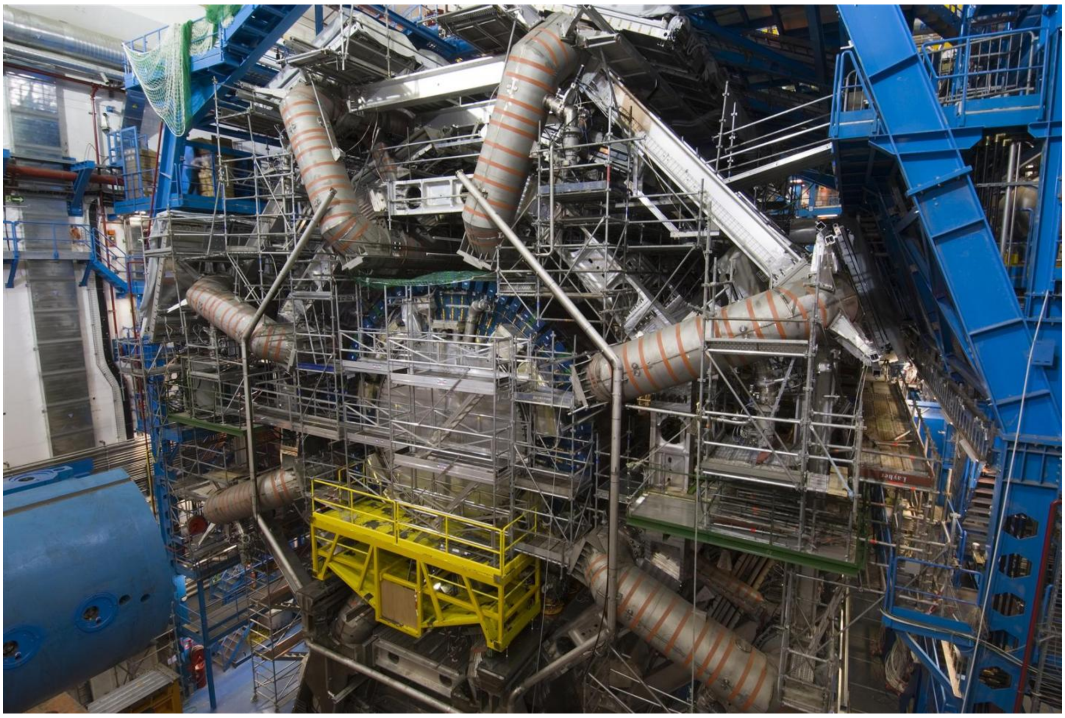

Figure 4.3: The magnet system on the ATLAS detector includes eight huge superconducting magnets (grey tubes) arranged in a torus (hoop) around the Large Hadron Collider beam pipe (Image: CERN)

Chapter 5

Gravity and Equations of motion

5.1 Acceleration due to gravity

Gravitation is the concept that all objects with mass are attracted to each other. Of the four fundamental forces in Physics, gravity is the weakest force (compared to electric, magnetic and the weak nuclear forces).

Gravitational theory states that any two objects can be thought of as being attracted to each other by the Gravitational force. This force is proportional to the amount of matter in each of the two objects and inversely proportional to the square of their distance apart.

When we drop an object, the chances are that the object has a smaller mass than the earth. So the earth appears to remain stationary and the object fall towards it. However, we know that both objects are actually moving towards each other. If we drop a 1kg weight from 1 metre, then the earth will move less than 1 million, million, million, millionth of a metre.

The Earth and the object can be thought of as being attracted to each other by their masses. So long as the object we are studying has much less mass than the Earth, the object will appear to fall to earth and earth will appear not to move towards the object. The object can be seen to accelerate towards the earth.

When an object falls to the ground, it's speed increases over time. It can be thought of as **accelerating** due to **gravity** (Figure 5.2).

In this experiment, an equation is needed which describes the gradient of (Figure 5.3). Luckily, this is all hidden in the Python script on the Raspberry Pi and so isn't necessary to know or understand it. All that is required is how high the trip switch is from the ball bearing and how long the ball bearing takes to fall. Easy as Pi. However, if you want to know the gorey details, read the comments in the Python script or see the Equations of motion section.

Figure 5.1: Babbage the Raspberry Pi bear about to skydive from the edge of space. At the start of the fall, Babbage's velocity increases over time. He is said to be accelerating due to gravity. (Eventually the Force due to his air resistance will equal the Force due to gravity and Babbage will have reached terminal velocity). In this experiment we are not going to worry about air resistance, but should we? Copyright Dave Akerman 2013.

5.1.1 Equation of motion used in the Python script

The equation of motion which connects a displacement (distance as a vector) and acceleration over time is:

$s = u \times t + \frac{1}{2} \times (a \times t^2)$

Where:

s = displacement in metres (m)
u = initial velocity in metres per second (ms^-1)
t = time in seconds (s)
a = acceleration as a vector in metres per second squared (ms^-2)

As the initial velocity u is zero when the ball bearing is first dropped, the equation becomes:

$s = (0 \times t) + \frac{1}{2} \times (a \times t^2)$

This explains the reason that Figure 5.2 looks like a $y = x^2$ graph rotated

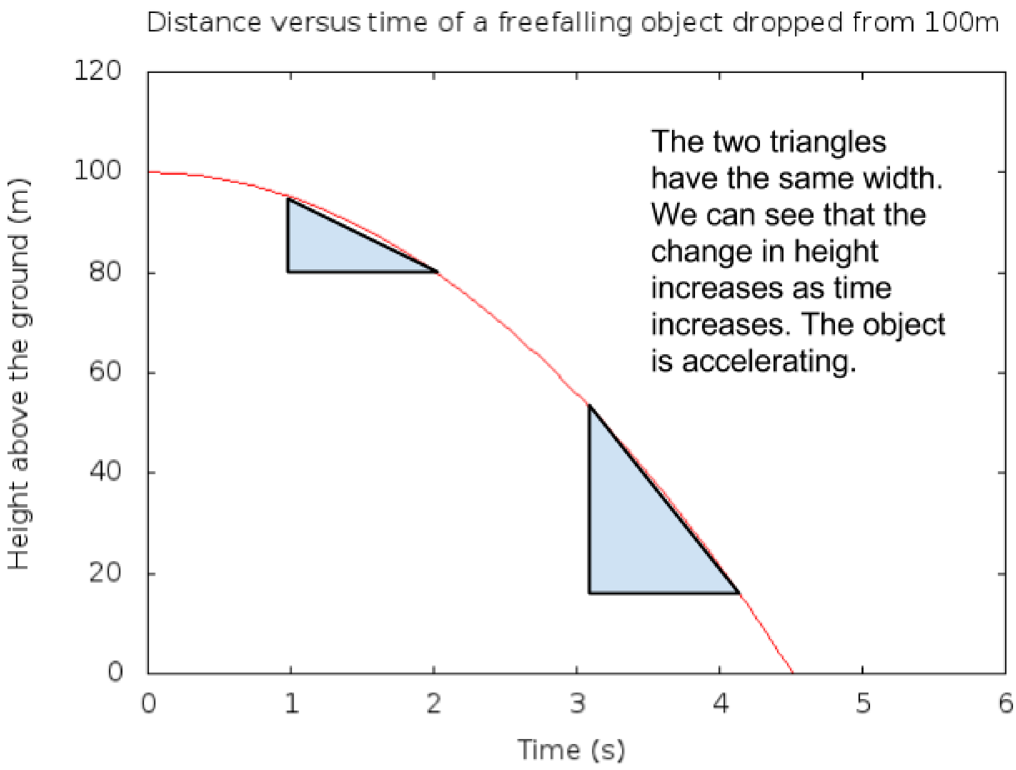

Figure 5.2: Distance time graph for an object in free fall. Does this look like anything you've ever seen in Maths?

through 90 degrees. That graph actually shows a relationship similar to $x = constant \times y^2$. The $constant$ is acceleration.

Therefore:
$s = \frac{1}{2} \times (a \times t^2)$

Arranging this equation for a gives:

$a = \frac{2 \times s}{t^2}$

So, to calculate the acceleration due to gravity, we multiply the distance fallen by two and divide by the square of the time to fall that distance. Of course this assumes no air resistance!

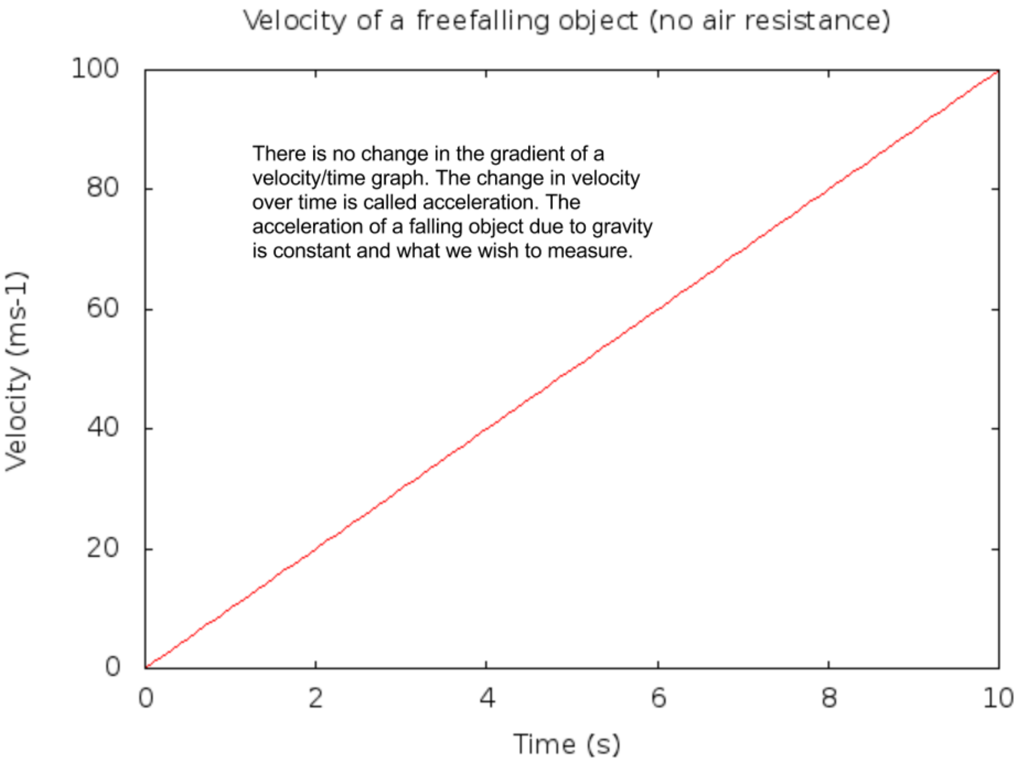

Figure 5.3: Velocity time diagram for an object in free fall

Chapter 6

Availability of the Python code and this document

Code available under a GPL licence: https://github.com/tommybobbins/PiFaceGravityExperiment

Many thanks to Craig Richardson for providing the LaTeX source for his wonderful book: **Minecraft Pi Programming with Python**