Raspberry Pi Powered Gravity Experiment

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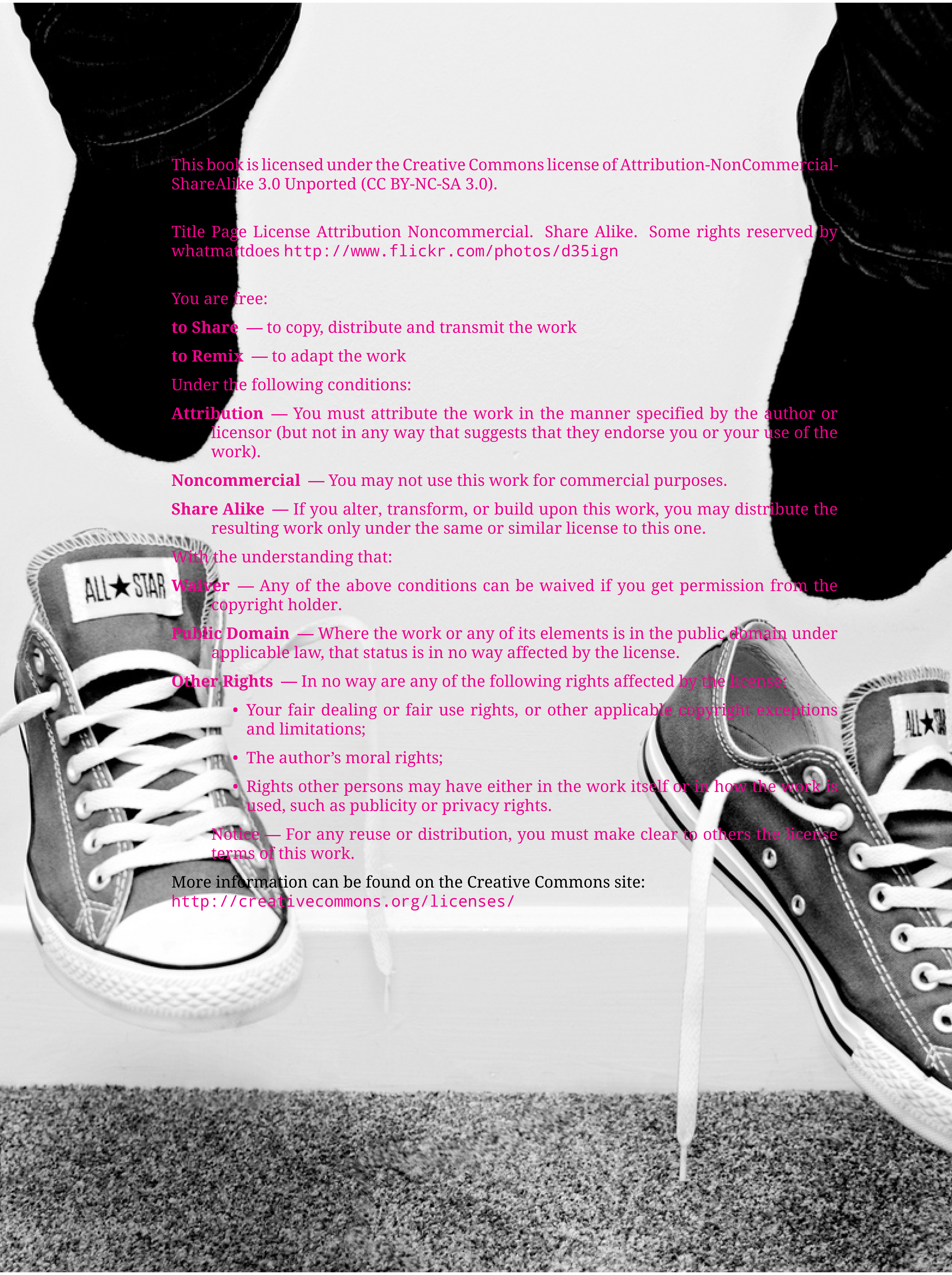
February 18, 2014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Chapter 1

The STEM Network Ogden Trust Challenge

1.1 Raspberry Pi Gravitational challenge sponsors

STEMNET
Science, Technology, Engineering and Mathematics Network

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Chapter 2

Electromagnets

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.

2.1 Uses of Electromagnets

Electromagnets are used in Recycling centres to sort the Iron from other metals. The relationship between magnetic fields and electric currents can be used in two different ways - we can generate motion from a current (motor) or generate a current from motion (dynamo/generator).

Incredibly powerful Electromagnets can be made, such as those found in MRI scanners [2.1]. 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.

Electromagnets are also incredibly useful to steer charged particles (ions, protons, electrons or more exotic particles). Daresbury use very large electromagnets in their Synchotron 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.

2.2 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). Attach the wire to a 1.5V potential difference - for this

Figure 2.1: Philips MRI in Sahlgrenska Universitetsjukhuset, Gothenburg, Sweden. Copyright: Jan Ainali 2008

experiment a size D cell (battery) will be used as these provide plenty of current for many repititions of the experiment.

If we want to control the electromagnet we need to be able to switch on and off the current flowing through the electromagnet. To control the electromagnet we use something called a Relay. This allows small electronic devices to control bigger electrical devices such as Motors 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. See Figure 3.7

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?

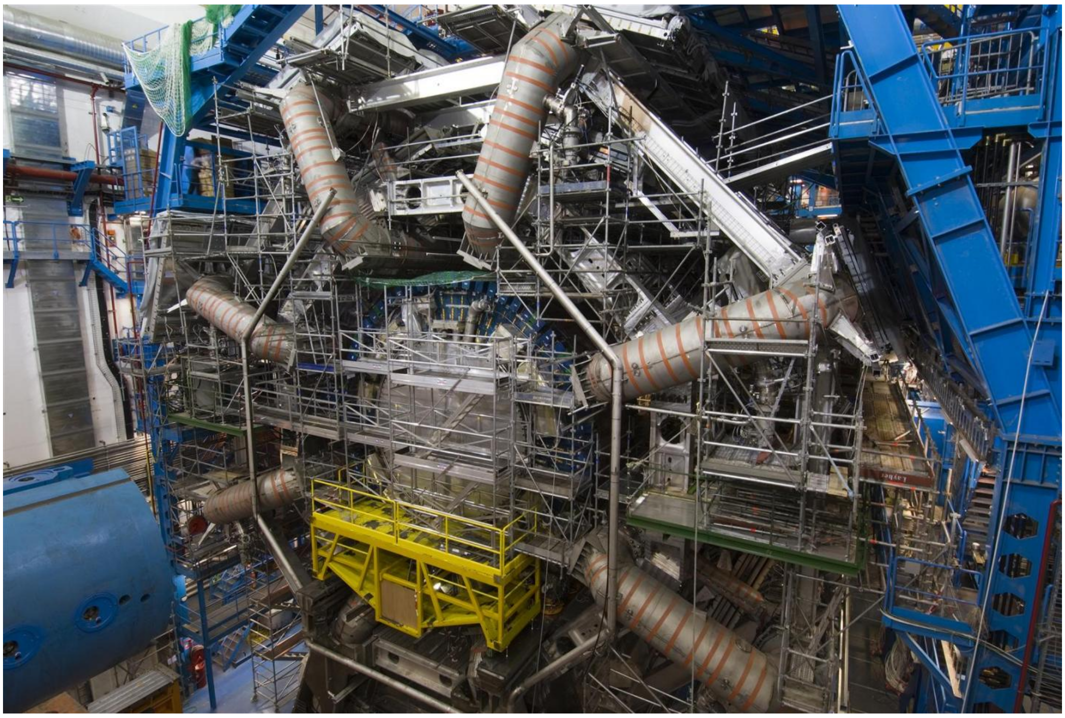

Figure 2.2: The magnet system on the ATLAS detector includes eight huge superconducting magnets (grey tubes) arranged in a torus (hoop) around the Large Hadron Collider beam pipe (Image: CERN)

Chapter 3

Raspberry Pi setup

3.1 Raspberry Pi

The Raspberry Pi (3.2) 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.

We are going to use the Raspberry Pi as an expensive, but highly accurate stopwatch. It is going to let go of the ball bearing and measure exactly how long after it let go it lands.

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, two USB sockets, a network socket and an HDMI socket for attaching to a monitor or TV.

3.2 Raspberry PiFace

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

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.

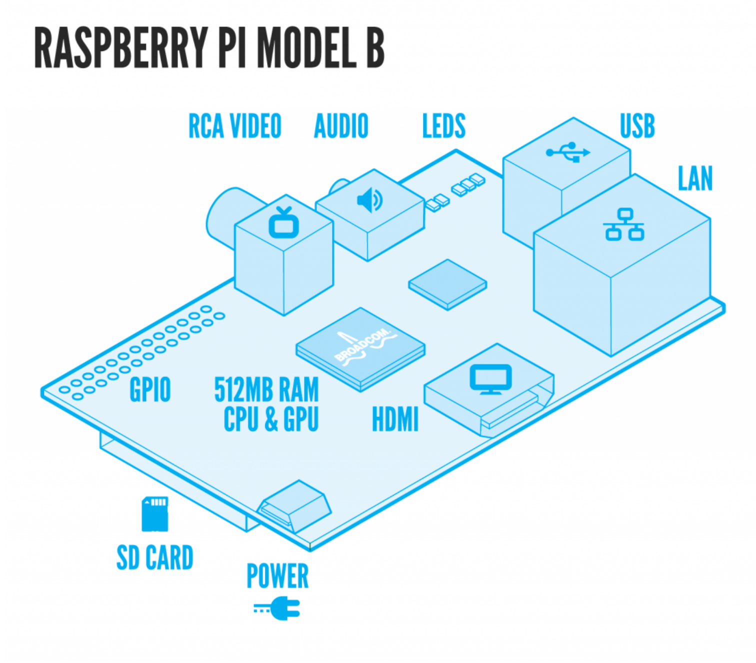

Figure 3.1: Raspberry Pi connections.

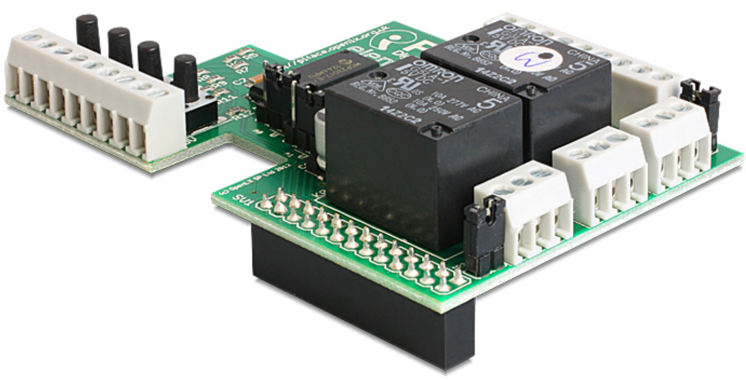

Figure 3.2: PiFace digital connections. Image taken from http://www.dlbilder.de/produkte/orig/513d9f110168c0.17822864.jpg. The GPIO pins are in the front of this image (2x13 connector). Look for 26 little solder teepees.

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?

3.3 Building a pressure plate switch

3.3.1 Materials Required

- Aluminium Foil.
- Scissors.
- 2 × Bendy Straws.
- 2 × 2m or more wires.
- 2 × blobs of blu-tack rolled into balls,
- Sellotape to stick the wires to the Aluminium foil.

3.3.2 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. See 3.3.

Cut two pieces of Aluminium foil to the same size as your straw rectangle. Ensuring that the aluminium is nice and flat. Lay one piece on the bottom of the straws 3.4 and attach one wire to it using sellotape. **Note that the wire is not the same at both ends. We want to use the end of the wire which has been stripped more**. Attach the other wire to the top piece 3.5 using sellotape. The tinfoil switch is almost complete 3.6. Using the small screwdriver, attach the switch to your PiFace as per 3.7.

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 will the height variable discussed in the next chapter.

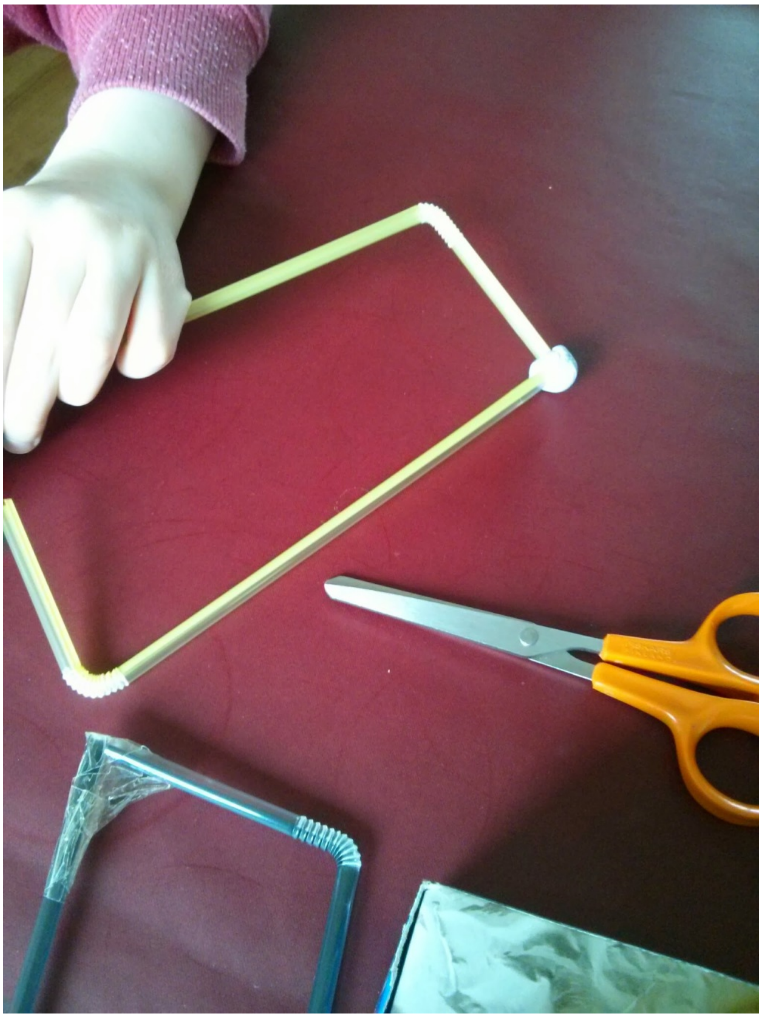

Figure 3.3: Create the frame for the pressure plate switch, by connecting two straws together with Blu-Tack. The straws act as an insulator between the two conducting layers of aluminium.

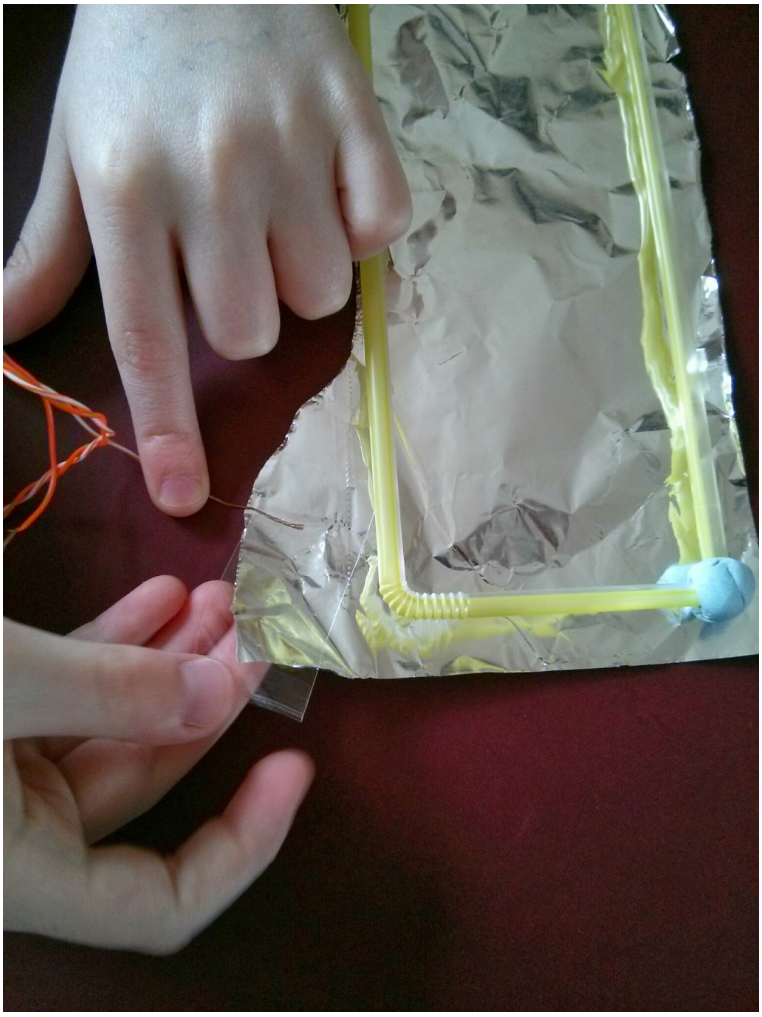

Figure 3.4: Attach a wire to the bottom piece of aluminium. Note this end of the wire has lots of copper exposed.

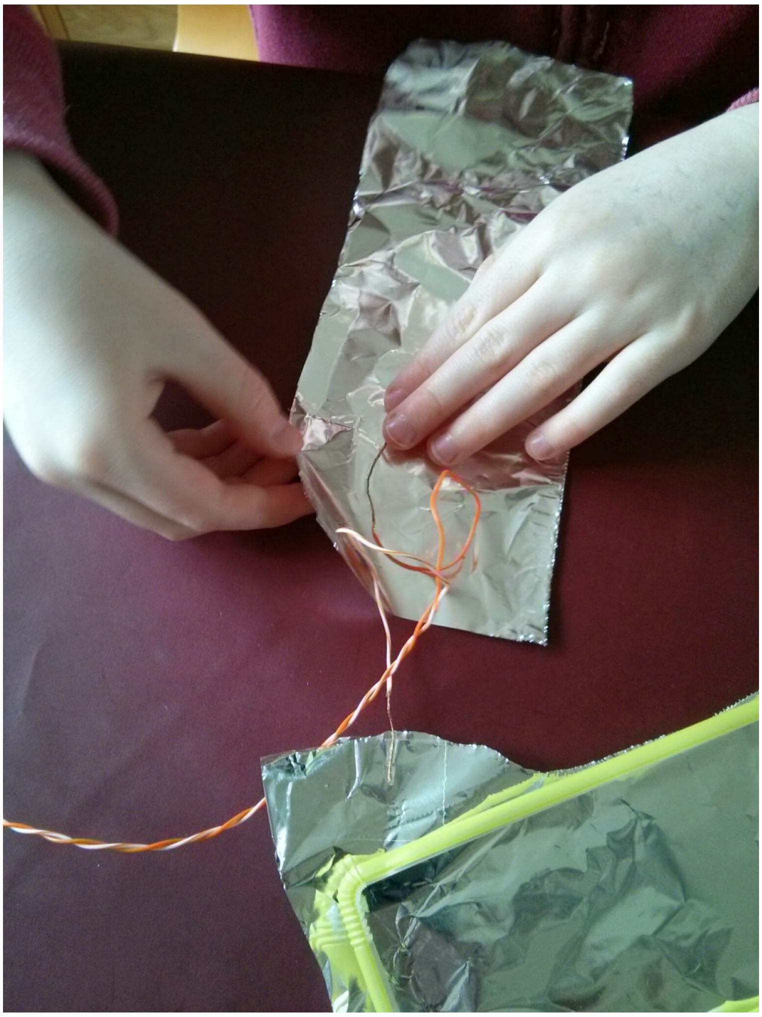

Figure 3.5: Attach a wire to the top piece of aluminium.

Figure 3.6: Tinfoil switch complete.

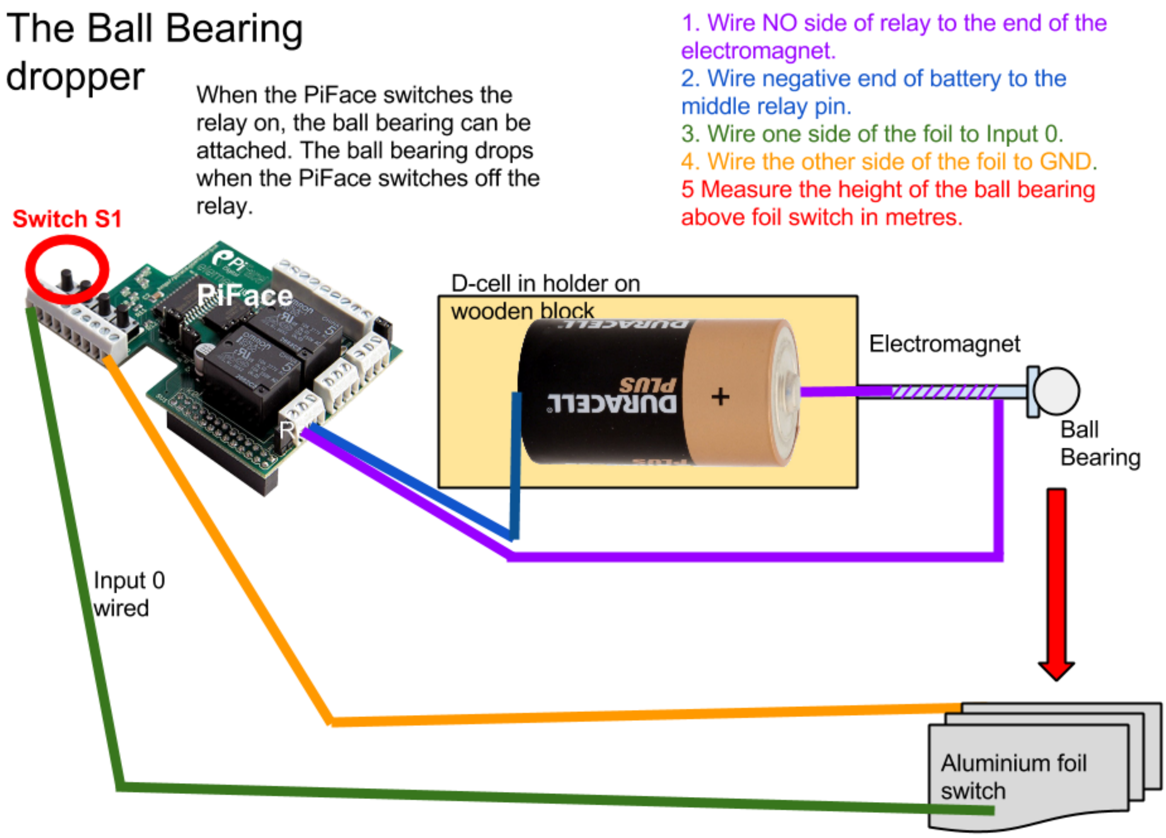

Figure 3.7: Electromagnet wiring diagram for the PiFace.

Chapter 4

Python programming

4.1 Editing and running a Python program

To edit the Python programs during this experiment, it is simple to use the IDLE program (IDLE stands for **I**ntegrated **D**eve**L**opment **E**nvironment) . Double click on the IDLE Icon on the desktop. See figure **??**.

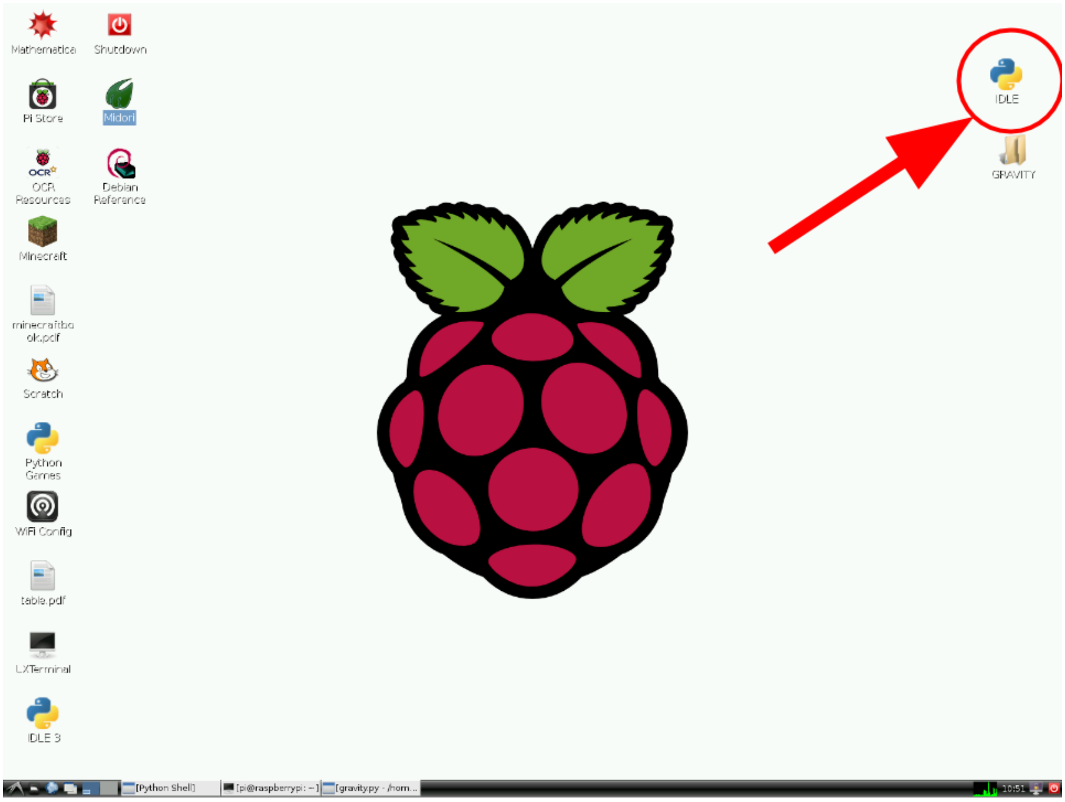

Figure 4.1: Starting IDLE

Open the gravity.py file using File→Open→Desktop→Gravity→gravity.py. See figure 4.2

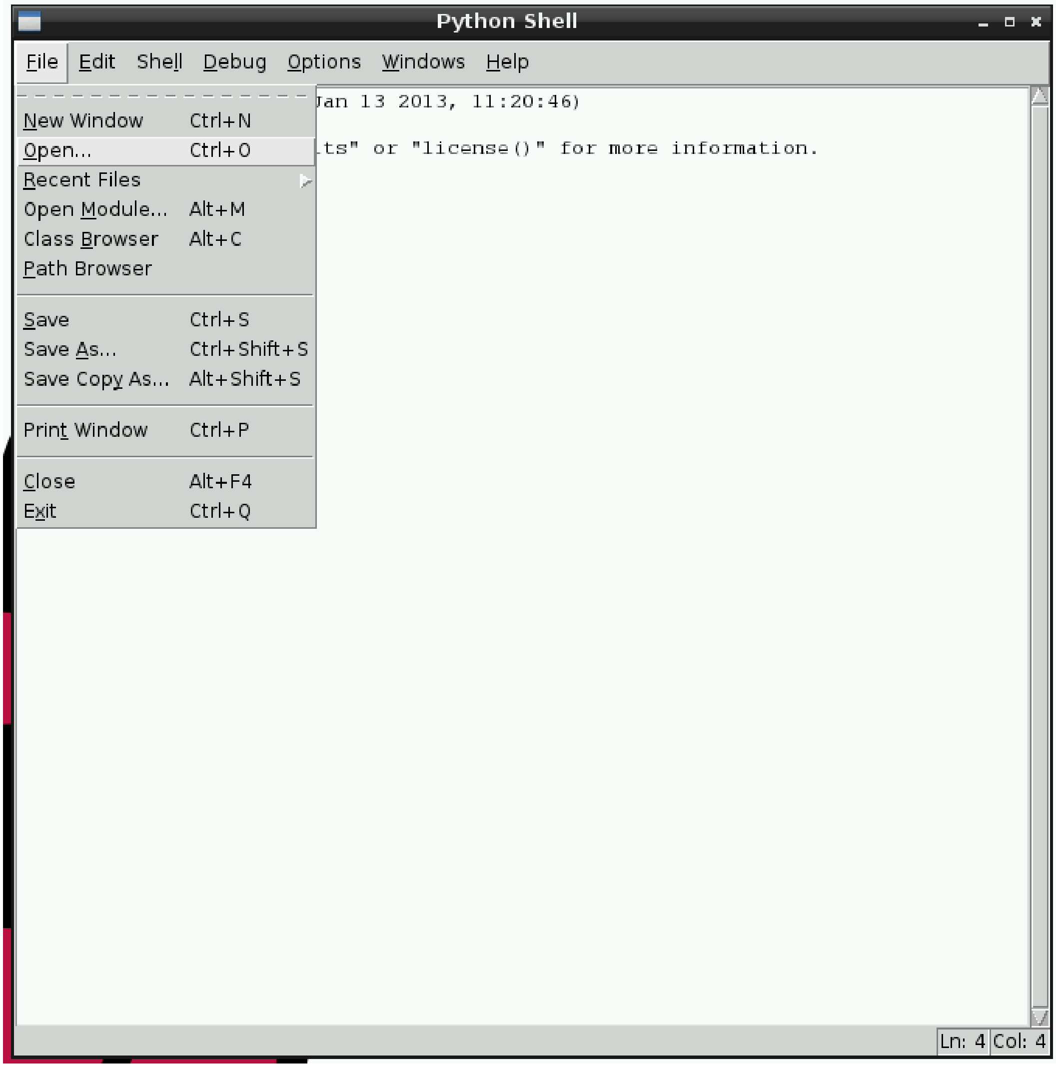

Figure 4.2: Opening files using IDLE

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, the variable allows the code to be better read by a human . See figure 4.3 for the location of **height** = **0.70** . Edit this to the appropriate height for the electromagnet from the pressure plate switch.

4.2 Running a Python program

Using the top menu, click on Run– >Run Module. See figure 4.3.

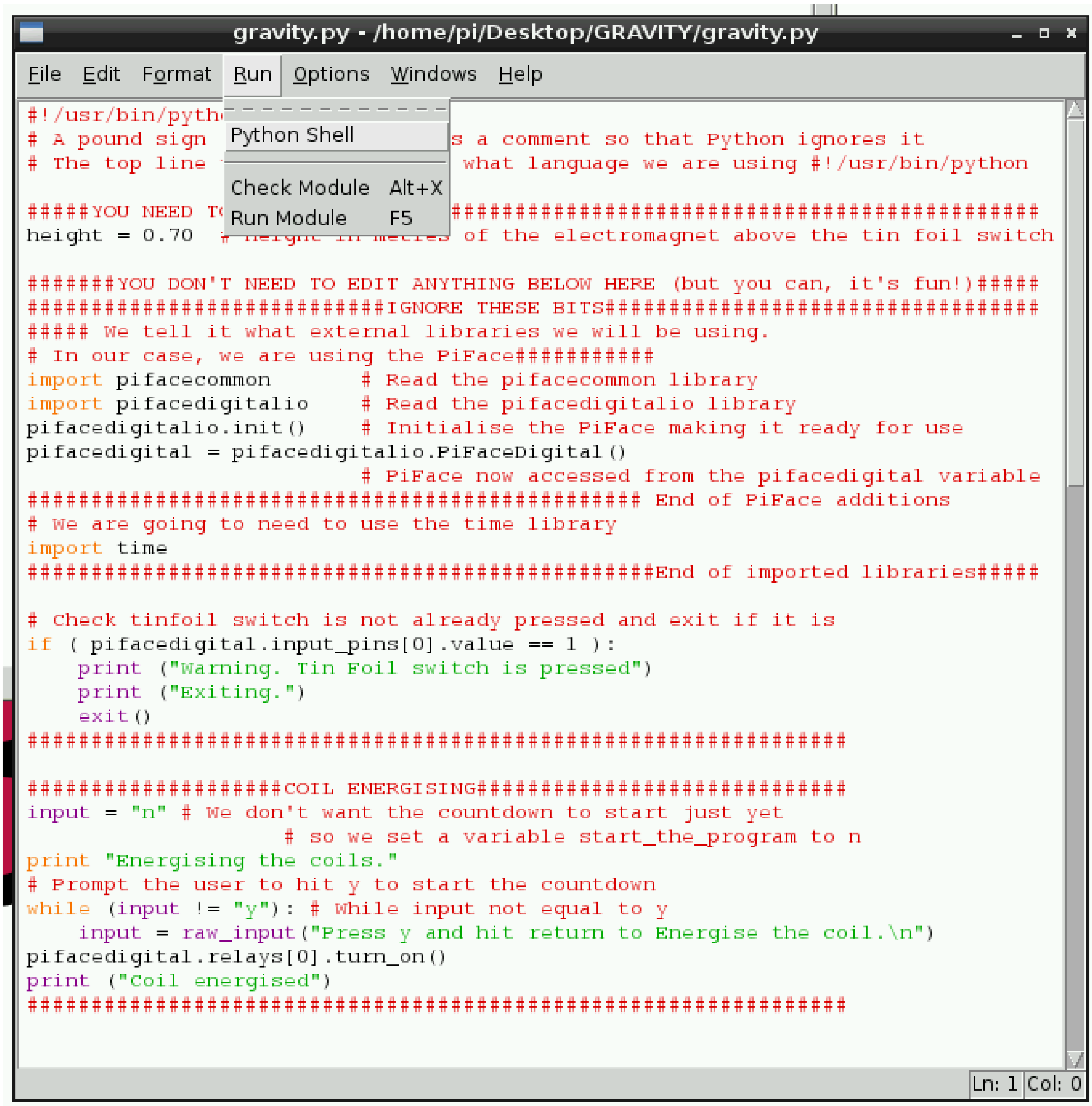

Figure 4.3: Running a program under IDLE.

Chapter 5

Gravity and Equations of motion

When an object falls to the ground, it's speed increases over time. It is said to **accelerate** due to **gravity**. See 5.2

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. Copyright Dave Akerman 2013.

In this experiment, an equation is needed which describes the gradient of [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.

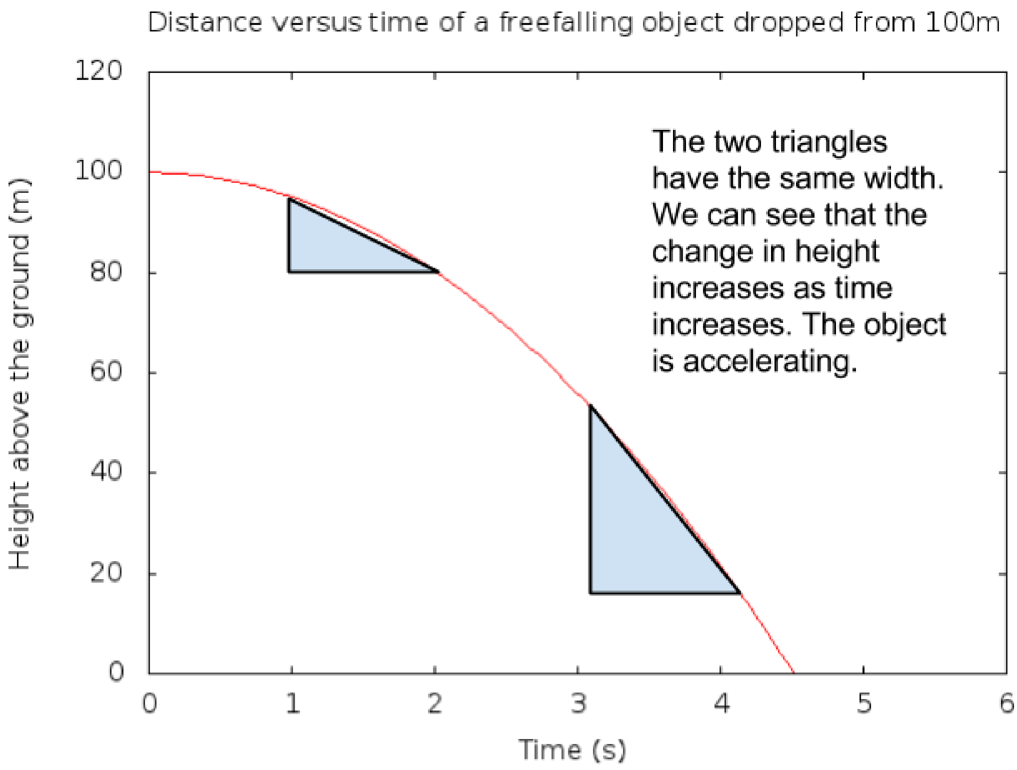

Figure 5.2: Distance time graph for an object in freefall. Does this look like anything you've ever seen in Maths?

5.0.1 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 veloctity 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:

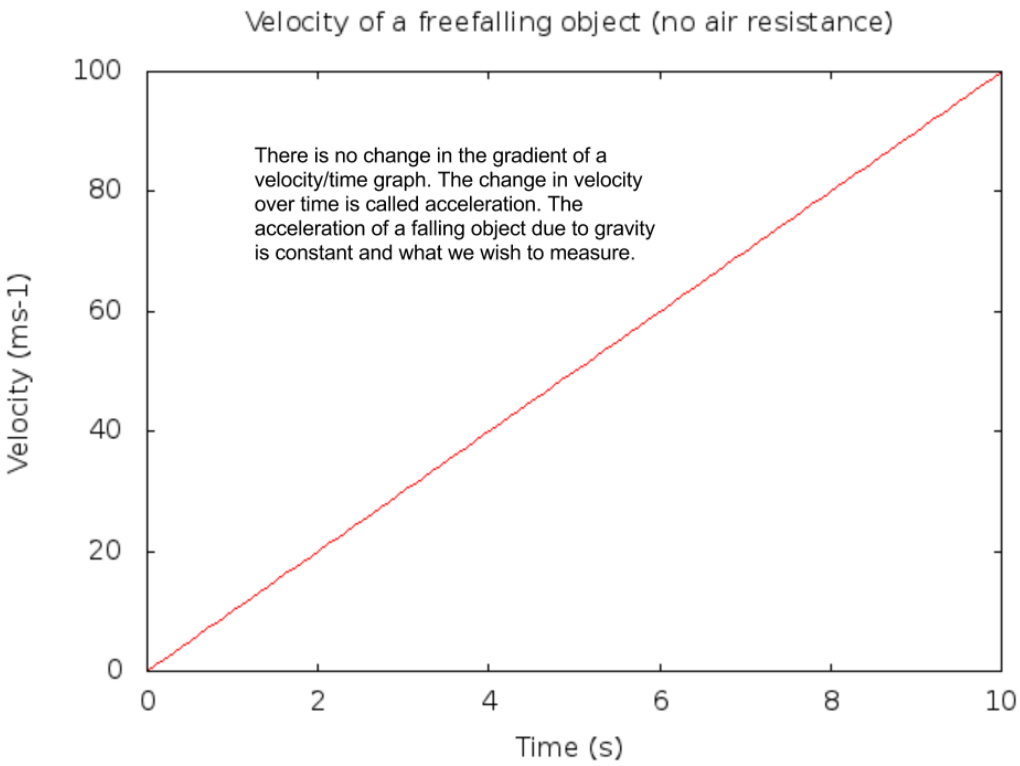

Figure 5.3: Velocity time diagram for an object in freefall

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

This explains the reason that Figure 5.2 looks like a $y = x^2$ graph rotated through 90 degrees. That graph actually shows a relationship similar to $x = constant \times y^2$.

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!

Chapter 6

Availability of the Python code

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**