AS-A2 Physics
Practical Endorsements

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Contents

1 Determine the acceleration of a freely falling object

Abstract

Using an electro-magnet and timer, calculate acceleration due to gravity of a steel ball bearing. Show that this acceleration is a constant - independent of height.

The acceleration of a free-falling object is dependent on the strength of the gravitational field strength where the object is falling.[1] Gravitational field strength; g, is measured in units of N/kg, which are equivalent units to that of velocity, ms^{-1}.

1.1 Equipment

- Electro-magnet
- Switch
- Electronic timer
- Ball bearing
- Ruler

1.2 Method

- Place the ball bearing onto the electro-magnet, so that it is perpendicular to the electronic switch/timer.
- Take the height; h, using a ruler and record in a table, where h is the height from the top of the switch, to the *bottom* of the ball bearing.
- Press the switch to turn off the electro-magnet and start the timer, the ball bearing will start to fail
- Once the ball bearing hits the sensor pad the timer will stop
- In a second column record the time displayed on the timer
- In a third column, calculate time squared
- Change the height; h, in increments of 0.05 meters and repeat previous steps at eight different heights, record times in the table.
- Plot a graph of height against t^2
- Calculate the gradient of the graph and show line of best fit

1.2.1 Control Variables

Use the same ball bearing, different shape and size of bearing will have different levels of air resistance that may effect time taken for ball to fall, therefore the same ball must be used for each test.

1.2.2 Risk Assessment

The ball bearing is heavy and could bounce off the sensor and potentially hit someone, as a precaution - stand up during practical so that ball bearing can be swiftly avoided if such a circumstance should occur.

[1] C. McDonagh, *Practical endorsement assessment 1 worksheet.* John Leggott College, 2016.

1.3 Results

Height (m)	Time (s)	Time^2
0.30	0.3055	0.0933
0.35	0.3257	0.1060
0.40	0.3444	0.1186
0.45	0.3612	0.1304
0.50	0.3790	0.1436
0.55	0.3946	0.1557
0.60	0.4112	0.1690
0.65	0.4217	0.1778

Table 1: Results from practical, with Time^2

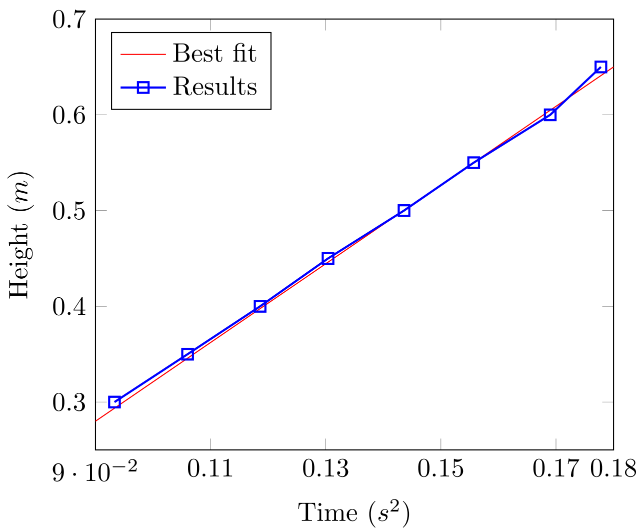


Figure 1: How height changes the bearings' time taken to fall from electro-magnet to electronic switch

1.4 Calculating acceleration due to gravity

1.4.1 TUVAS grid

T	U	V	A	S
t	0	?	g	h

1.4.2 Finding g

Substituting values into; $s = ut + \frac{1}{2}at^2$ gives $h = \frac{1}{2}gt^2$. Comparing this with $y = mx + c$, the gradient of the graph can be related of h against t^2 to acceleration due to gravity, $m = \frac{1}{2}g$.

$$\Delta h = 0.65 - 0.30 = 0.35m \tag{1}$$
$$\Delta t = 0.1778 - 0.09333 = 0.08447 \tag{2}$$
$$m = \frac{dh}{dt} \implies \frac{0.350}{0.08447} = 4.142 \tag{3}$$
$$m = \frac{1}{2}g \tag{4}$$
$$g = 2m \implies 4.142 \times 2 \tag{5}$$
$$\therefore g = 8.284ms^{-2} \approx 9.81ms^{-2} \tag{6}$$
$$\tag{7}$$

The error between measured and actual:

$$error = 100 - \left(\frac{8.284}{9.81} \times 100\right) = 15.5\% \tag{8}$$

2 Determine electrical resistivity of a material

Abstract

By varying length of a wire, thus changing its resistance, determine its resistivity by plotting a graph of resistance against length.

It is often useful to know the resistivity of a metal. Unlike resistance, which varies based on the dimension of a material, the resistivity of a material is constant. Measured in Ohmmeters (Ωm), it is related to the resistance of a material in the equation:[2]

$$R = \frac{\rho l}{A}$$

Where:

- ρ, rho: Resistivity (Ωm)
- R: Resistance (Ω)
- l: Length (m)
- A: Cross-sectional area (m^2)

Resistivity represents the resistance across two opposite faces of a cubic meter of material. Resistivity is a measure how resistive a material is. This means that resistivity is the inverse of conductivity, thus we would expect that the resistivity of a length of metallic wire would have very low resistivity.[3]

The co-efficient of resistivity of steel is around $1.51 \times 10^{-6} \Omega m$, thus the calculated result should be around this value.[4]

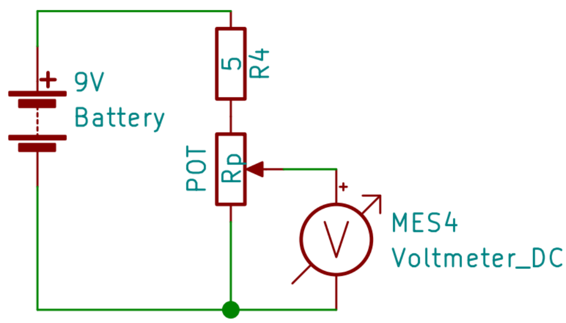


Figure 2: Circuit diagram

Potentiometer put in place of length of wire where length varied via flying wires in Figure 2.

2.1 Equipment

- Power supply
- Wires
- Ammeter
- Crocodile clips
- Voltmeter

[2]M. Hudson, *Edexcel as physics (student book), Electrical resistivity*. Pearson, 2009.

[3]S. Science. (2017). Electrical current resistance and resistivity, [Online]. Available: `http://resources.schoolscience.co.uk/CDA/16plus/copelech2pg1.html` (visited on 03/07/2017).

[4]E. Toolbox. (2017). Electrical current resistance and resistivity, [Online]. Available: `http://www.engineeringtoolbox.com/resistivity-conductivity-d_418.html` (visited on 03/07/2017).

- Ammeter
- Length of metal wire
- Vernier Caliper
- Protective resistor

2.2 Method

- Construct the circuit as shown in Figure 2.
- Measure the cross-sectional area of the wire, A, using vernier calipers
- By varying the distance at which the wire is connected to make a circuit loop with a flying wire, the effective resistance of the wire can be altered
- Starting from the base of the wire, increment the distance from which a circuit loop is made in 0.02m increments, increasing the effective resistance of the wire as the current has flow further through the wire
- Measure the voltage across the wire and current flowing through the entire circuit.
- Calculate the resistance of the wire via $R = \frac{V}{I}$, where R: Resistance, V: Voltage across wire, I: Current through the circuit.
- For each length of wire, calculate the resistance
- Plot a graph of resistance against length over cross-sectional area .
- Calculate the resistivity of the wire by calculating the gradient of the line, $\frac{R}{\frac{l}{A}}$.[5]

2.3 Measurements

- **Diameter**: $3 \times 10^{-4} m$
- **Cross-sectional area**: $2.83 \times 10^{-7} m^2$

2.4 Results

Length of wire (m)	Voltage(V)	Current (A)	Resistance (Ω)	$\frac{l}{A}$
0.30	0.366	0.372	0.984	1.06+06
0.28	0.342	0.373	0.917	992907.8
0.26	0.322	0.375	0.859	921985.8
0.24	0.300	0.377	0.796	851063.8
0.22	0.284	0.378	0.751	780141.8
0.20	0.256	0.380	0.674	709219.8
0.18	0.239	0.378	0.632	638297.8
0.16	0.208	0.382	0.545	567375.8
0.14	0.183	0.384	0.477	496453.9
0.12	0.169	0.385	0.439	425531.9
0.10	0.137	0.388	0.353	354609.9

Table 2: Results of experiment

[5] Science, *Electrical current Resistance and resistivity.*

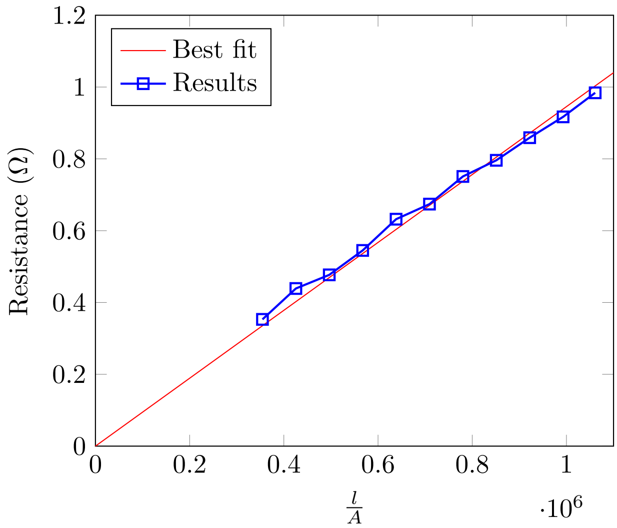


Figure 3: Resistance of wire against length

2.5 Calculating resistivity of the wire

The gradient of the graph R against $\frac{l}{A}$ is equal to the resistivity, ρ.

$$m = \frac{y - y_1}{x - x_1} = \rho \tag{9}$$

$$\rho = \frac{0.984 - 0.353}{1061032 - 354609} \tag{10}$$

$$\rho = 1.893 \times 10^{-6} \Omega m \approx 1.51 \times 10^{-6} \Omega m \tag{11}$$

3 Determining E.M.F. and Internal Resistance of an Electrical Cell

Abstract

Conduct an experiment to determine the E.M.F and internal resistance of an electrical cell graphically from collected results.

EMF ($\mathcal{E}$), internal resistance (r) and potential difference (V) are linked in the following equation[6].

$$V = \mathcal{E} - Ir$$

$Ir = \Delta V$, i.e. the lost volts.

To find the EMF and internal resistance, a circuit must be created that can increase/decrease the rate of flow of current.

Potential difference is lost as the current passes through the cells' internal resistance, resulting in *lost volts* - the wasted energy used in overcoming the internal resistance per unit of charge.

$$V = IR$$

If V is to remain constant as R increases, I must change inversely.

3.1 Equipment

- Electrical cell
- Voltmeter
- Ammeter
- Variable resistor (rheostat)
- Wire and crocodile clips

3.2 Method

- Set up the circuit as shown in Figure 4

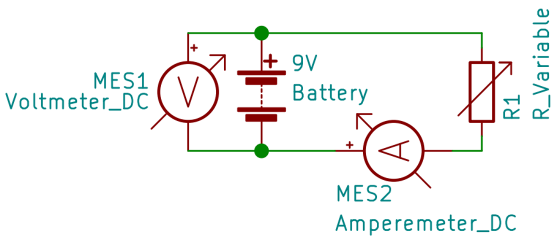


Figure 4: Circuit diagram

The voltmeter must be in parallel with the cell, otherwise no current will flow. The ammeter must be in series with the cell, so that the current flowing through the circuit and thus through it can be recorded.

- Move the slider on the rheostat so that it's resistance is 0Ω
- Move the slider incrementally by 2cm each time so that it's resistance increases, note the voltage and current show on the voltmeter/ammeter.

[6] B. Bitesize. (2014). Energy and Voltage e.m.f. and internal resistance, [Online]. Available: `http://www.bbc.co.uk/bitesize/higher/physics/elect/energy_volts/revision/3/` (visited on 03/06/2017).

3.3 Results

Voltage (V)	Current (mA)
4.86	404.3
4.87	396.3
4.88	387.4
4.89	380.9
4.90	373.1
4.91	359.6
4.92	350.8
4.94	332.5
4.95	321.9
4.97	305.9
4.98	300.2
4.99	287.0
5.00	280.0

Table 3: Terminal potential difference w/ current

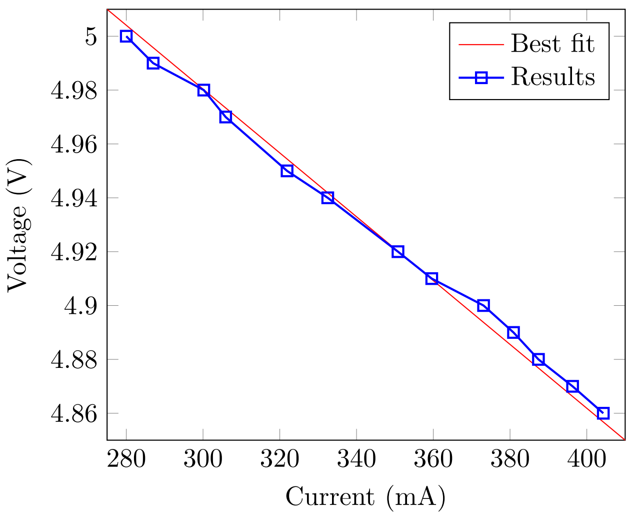


Figure 5: How voltage varied with current in the experiment

3.4 Calculating EMF and internal resistance using the results

3.4.1 Calculating EMF

The EMF of a V/I graph is at the point where the line intercepts the y-axis, therefore the equation of the line must be found. The line will intercept the y-axis when $x = 0$, giving us the EMF.

The gradient of a line is given by:

$$m = \frac{y_1 - y}{x_1 - x} \tag{12}$$

And using the largest values, the gradient is:

$$m = \frac{5.00 - 4.86}{280.0 - 404.3} \tag{13}$$

$$= \frac{0.14}{-124.3} \tag{14}$$

$$m = \frac{-7}{6215} \tag{15}$$

To get the equation of the line, and thus the y-intercept:

$$y - y_1 = m(x - x_1) \tag{16}$$
$$y_1 = 5, x_1 = 280 \tag{17}$$
$$y - 5 = \frac{-7}{6215}(x - 280) \tag{18}$$
$$6125y - 30625 = -7(x - 280) \tag{19}$$
$$6125y - 30625 = -7x + 1906 \tag{20}$$
$$6125y + 7x = 32531 \tag{21}$$
$$\tag{22}$$
$$\text{when x=0} \tag{23}$$
$$6125y = 32531 \tag{24}$$
$$y = \frac{32531}{6125} \tag{25}$$
$$= 5.311 \tag{26}$$

5.311 is the y intercept of the graph and thus is the EMF, in Volts.

3.4.2 Calculating internal resistance

The gradient of the line is equal to the negative of the internal resistance of the cell. Using the previously calculated gradient, the internal resistance of the cell is equal to:

$$m = \frac{-7}{6215} \tag{27}$$
$$r = -\left(\frac{-7}{6215}\right) \tag{28}$$
$$r = 1.1428 \times 10^{-3}\Omega \tag{29}$$

3.5 Proof

Working backwards to find the voltage of the cell using the derived values.

$$V = \mathcal{E} - Ir \tag{30}$$
$$V = 5.33 - (404.31 \times 1.14281 \times 10^{-3}) \tag{31}$$
$$V = 4.487V \tag{32}$$
$$4.487V \approx 4.86V \tag{33}$$

4.86V was the recorded voltage when 404.3mA of current was flowing.
These values could also be found by rearranging the EMF equation into $y = mx + c$, e.g.

$$V = -rI + \mathcal{E} \tag{34}$$
$$y = mx + c \tag{35}$$

4 Determining the viscosity of Glycerin

Abstract

Conduct an experiment to determine the co-efficient of viscosity of Glycerin by using a ball bearing and finding its terminal velocity.

The co-efficient of viscosity in a fluid is linked via Stoke's Law;

$$F = 6\pi\eta r v$$

Where:

- F: force (N)
- r: radius of sphere (m)
- η: co-efficient of viscosity (Nsm^{-2})
- v: velocity (ms^{-1})

Stokes law only holds for the following conditions:

- A small sphere falling slowly
- Laminar flow, i.e.
  - Streamlines are parallel to each other, velocity at any given time at the streamlines is equal.

As a sphere reaches terminal velocity, upthrust and the force of drag becomes equal to the weight, therefore:

$$\mathcal{U} + F_{drag} = W \tag{36}$$

$$\frac{4}{3}\pi r^2 P_f g + 6\pi\eta r v = mg \tag{37}$$

Where:

- P_f = density of fluid

If all other variables are known, the equation can be re-arranged to find η.

$$\eta = \frac{2r^2 g\left(P_o - P_f\right)}{9V_t}$$

4.1 Equipment

- Large tube
- Steel ball bearing
- Glycerin
- Weighing scale
- Stopwatch
- Ruler
- Marker

4.2 Method

- Place a mark, mark A, at the top of the tube at the initial drop point - and another 20cm away, mark B.
- Record time taken for ball bearing to travel to the bottom of the tube
- Calculate average velocity
- Repeat this and incrementing the height at which the bearing is dropped each time by increasing the distance between mark A and B by 20cm, and calculate the average velocity via $s = ut$
- When the average velocity has stopped increasing, terminal velocity has been reached
- Drop the ball bearing three times; for reliability; and calculate the average velocity for each.
- The average of these is the terminal velocity of the ball bearing.

4.3 Results

Distance (m)	Time (s)	Avg. time (s)	Avg. velocity (ms^{-1})
0.694	7.69	7.893	0.0879
0.696	8.05		
0.693	7.94		
0.674	7.47	7.545	0.0893
0.675	7.62		
0.673	7.62		
0.651	7.25	7.250	0.0887
0.652	7.22		
0.650	7.24		

Table 4: Results from experiment

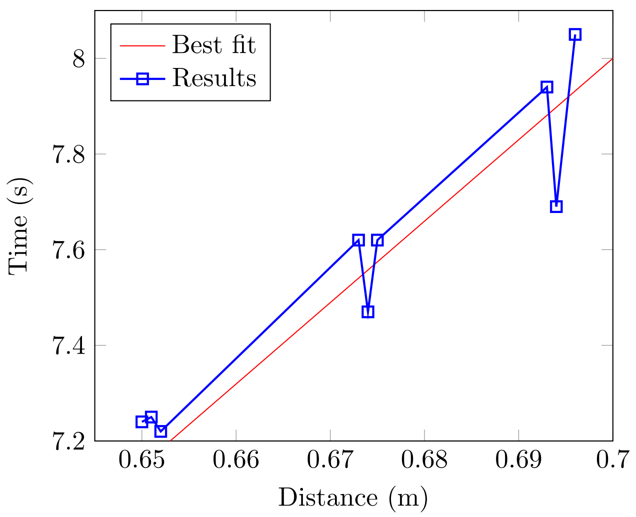


Figure 6: How distance affected time taken for ball bearing to fall through liquid

4.4 Calculating the viscosity of Glycerin, η

4.4.1 Deriving viscosity equation

For terminal velocity, sum of the forces acting on a body must be equal to zero.

$$F_a + F_b + ... + F_x = 0$$

There are three forces acting on a small spherical object traveling through a fluid at terminal velocity, weight, upthrust and viscous drag, denoted F_w, F_u, F_d.

$$F_w + F_u + F_d = 0$$

$$F_w = mg = \frac{4}{3}\pi r^3 \rho_o g \tag{38}$$

$$F_u = \frac{4}{3}\pi r^3 \rho_f g \tag{39}$$

$$F_d = 6\pi\eta r v_t \tag{40}$$

Upthrust and viscous drag always work in opposition to motion, such that:

$$F_u + F_d - F_w = 0 \tag{41}$$

$$\frac{4}{3}\pi r^3 \rho_f g + 6\pi\eta r v_t - \frac{4}{3}\pi r^3 \rho_o g = 0 \tag{42}$$

Expanding and canceling...

$$6\cancel{\pi}\eta r v_t = \frac{4}{3}\cancel{\pi} r^3 (\rho_o - \rho_f) g \tag{43}$$

$$\eta = \frac{2r^2 g\,(\rho_o - \rho_f)}{9v_t} \tag{44}$$

Density of Glycerin at 20 degrees is around $1260kgm^{-1}s^{-1}$.[7]

Density of the ball bearing can be calculated via finding its volume and mass, and dividing by such.

4.4.2 Measurements

- Diameter of ball bearing: $4.4 \times 10^{-3}m$
- Mass of ball bearing: $0.25g$

$$v_{ball} = \frac{4}{3}\pi r^3 \tag{45}$$

$$v_{ball} = \frac{4}{3}\pi \frac{4.4 \times 10^{-3}}{2}^{3} = 3.56 \times 10^{-7} \tag{46}$$

$$d = \rho_o = \frac{m}{v} \implies \frac{0.25}{3.56 \times 10^{-7}} = 7006.53 \tag{47}$$

$$\tag{48}$$

The terminal velocity is calculated by finding the average of the two closer average velocities captured in the practical, shown in table 4.

[7] eCourses. (2017). Fluid mechanics - theory, [Online]. Available: http://www.ecourses.ou.edu/cgi-bin/eBook.cgi?topic=fl&chap_sec=01.1&page=theory (visited on 03/07/2017).

$$V_t = \frac{0.0893 + 0.0887}{2} = 0.0892ms^{-1} \tag{49}$$

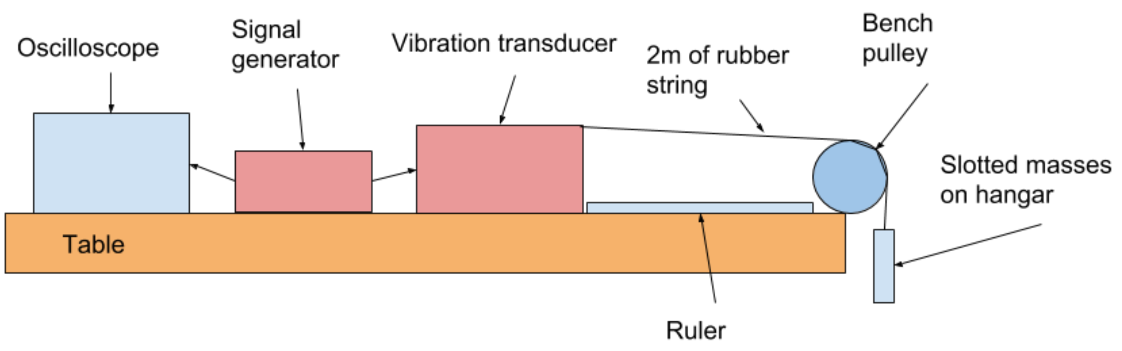
Now that all variables are known, they can be substituted into the equation to find η.

$$\eta = \frac{2\left(\frac{4.4\times10^{-3}}{2}\right)^2 \times 9.81 \times (7006.53 - 1260)}{9(0.0893)} \tag{50}$$

$$\eta = 1043.095153kgm^-1s^-1 \tag{51}$$

$$\eta \approx 1043.1kgm^-1s^-1 \tag{52}$$

5 Effect of tension and length on frequency of 2nd Harmonic (1st Overtone)



5.1 Equipment

- Vibration generator
- Nylon/"elastic" rope, 2 meters
- Signal generator
- Bench pulley
- Slotted masses (increments of 100g) and hangar
- Stand
- Oscilloscope

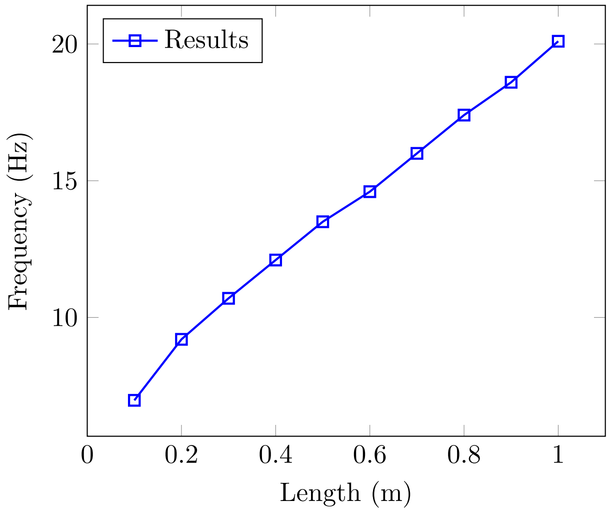
5.2 Method

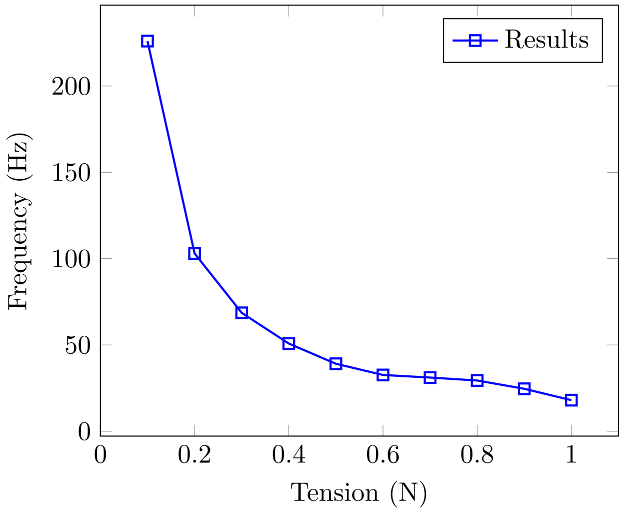
-

5.3 Results

Frequency of 2nd Harmonic (Hz)	Length (m)	Frequency of 2nd Harmonic (Hz)	Tension (N)
226	0.1	6.97	0.1
103	0.2	9.20	0.2
68.6	0.3	10.7	0.3
50.8	0.4	12.1	0.4
39.1	0.5	13.5	0.5
32.6	0.6	14.6	0.6
31.1	0.7	16.0	0.7
29.4	0.8	17.4	0.8
24.6	0.9	18.6	0.9
18.0	1.0	20.1	1.0

Table 5: Effect of length/tension of rope on frequency of 2nd harmonic





5.4 Calculating mass per unit length, μ

The mass per unit length of a wire can be calculated via:

$$v = \sqrt{\frac{F}{\mu}} \tag{53}$$

Rearranging for μ,

$$\mu = \frac{F}{v^2} \tag{54}$$

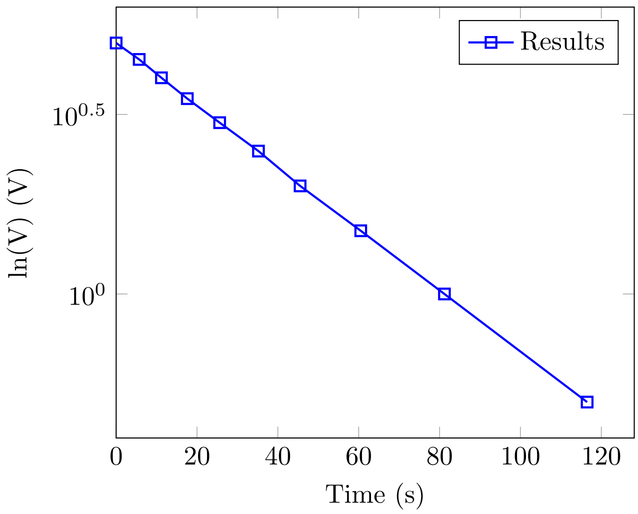
Where $\mu = \frac{M}{L}$, the mass, M, per unit length, L.

6 Analyzing the potential difference of a capacitor as it discharges across a resistor

6.1 Large Capacitor

Voltage (V)	Time (s) 1	2	Mean time (s)
5.0	0	0	0
4.5	5.8	5.6	5.7
4.0	11.7	10.7	11.2
3.5	18.0	17.1	17.6
3.0	26.2	25.0	25.6
2.5	35.3	35.1	35.2
2.0	46.3	44.9	45.5
1.5	61.0	60.0	60.5
1.0	82.0	80.4	81.2
0.5	117.0	116.0	116.5
0.0	290.0	291.0	290.5

Table 6: Results from experiment



6.1.1 Calculating capacitance from the time constant

$$V = V_o e^{t \frac{-1}{RC}} \tag{55}$$
$$ln(v) = -\frac{t}{RC} + ln(V_o) \tag{56}$$
$$y = xm + c \tag{57}$$
$$m = \frac{y - y_1}{x - x_1} \tag{58}$$
$$\Rightarrow \frac{5-0}{0-290.5} = 0.01721 \tag{59}$$
$$\frac{-1}{RC} = 0.01721 \tag{60}$$
$$\therefore C = \frac{1}{470 \times 10^3 \times 0.01721} \tag{61}$$
$$C = 123.6 \times 10^-6 \Rightarrow 123\mu F \approx 100\mu F \tag{62}$$

There were no markings on the capacitor, therefore one must assume the capacitance has a value of $C \pm (+80\%, -20\%)$.[8] The possible values of capacitance are therefore:

$$98.9\mu F < C < 222.5\mu F \tag{63}$$
$$C = 123.61\mu F \tag{64}$$

Therefore the capacitor is within its tolerance.

6.2 Small Capacitor

6.3 Equipment

- Electrolytic capacitors
- PicoScope Digital Oscilloscope
- Resistor, $\frac{1}{4}W$, Ω

6.4 Method

- Construct the circuit as shown in Figure
- Charge up the capacitor by closing the switch
- Observe the change in voltage on the digital oscilloscope display.
- Discharge the capacitor by opening the switch, the capacitor will now discharge through the resistor
- Note down the time taken to discharge from $+V_s$ to $0V$.
- Repeat with several different value electrolytic capacitors

6.4.1 Control Variables

- Resistor resistance value
- Power supply voltage

[8] Robotoid. (2018). Understanding capacitor markings, [Online]. Available: http://www.robotoid.com/appnotes/electronics-capacitor-markings.html (visited on 05/09/2018).

6.4.2 Risk Assessment

- Ensure that the electrolytic capacitor is placed in the correct polarity, may explode if in the opposite polarity
- Ensure that the supply voltage does not the capacitors specified maximum rating

6.5 Results

The time taken to discharge the capacitor is $5RC$, where R: Parallel resistance, C: Capacitance,

7 Calibration of a NTC Thermistor

7.1 Equipment

- Thermistor
- Ohmmeter and leads
- Alcohol thermometer
- Ice / boiling water
- Stirrer
- Beaker containing hot water

7.2 Method

- Add 150ml of boiling water to the beaker. Place the thermometer and thermistor together in the water.
- Take a reading of the resistance of the highest multiple of 5°C preset.
- Stir the water between every reading, keeping the thermistor and thermometer close together.
- Stop taking readings when the temperature reaches room temperature.

7.3 Results

Temperature (°C)	Resistance (Ω)
75	710
70	850
65	1020
60	1200
55	1520
50	1780
45	2270
40	2800
35	3470
30	3830

Table 7: Table of results

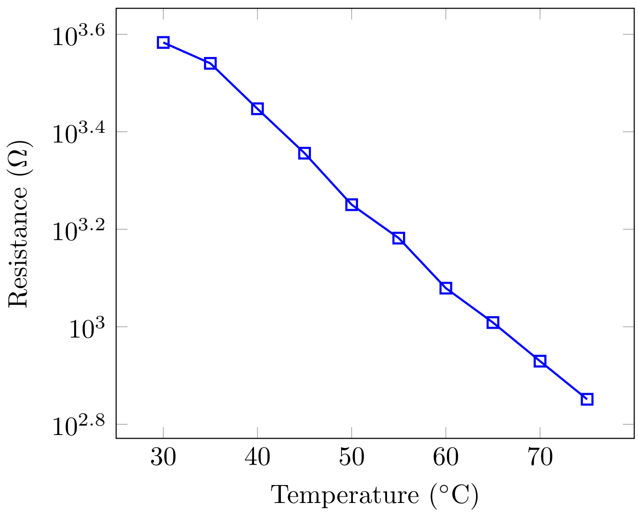


Figure 7: How temperature affects the resistance of the NTC thermistor

7.4 Designing the potential-divider

A potential divider consists of two resistors in series, with a differential voltage in between the two, which is created in a ratio of the resistances.

In order to create a 3V output using a 6V supply, one must calculate what resistor values are needed. With a desired 3V output from a 6V supply, this ratio is 1:1, i.e. 3V dropped across each resistor. This only occurs when each resistor is equal in value, thus the voltage across them is split.

We can find the desired resistor values for a 3V output at 40C graphically. We can see at 40C the resistance of the thermistor is 2800Ω. If R_1 is the thermistor, then R_2 is the series resistor, thus R_2 must also be 2800Ω.

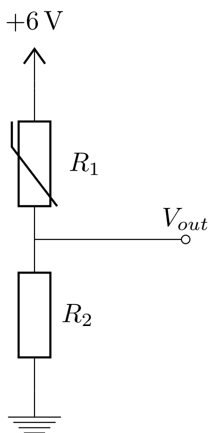


Figure 8: Designed potential divider

7.5 Testing the circuit

7.5.1 Equipment

- 6V power supply
- Voltmeter
- Thermistor (same as prior)
- Resistors, 2.7kΩ and 100Ω

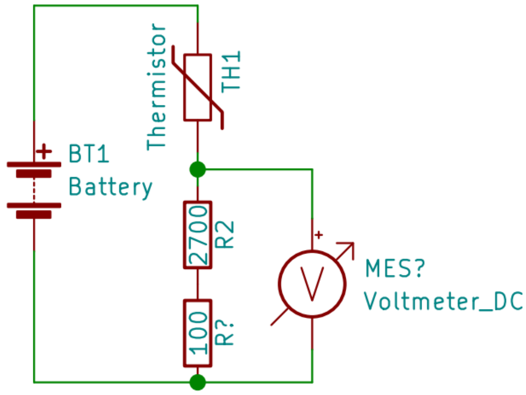


Figure 9: Circuit diagram

7.6 Estimating uncertainty and considering improvements

8 Determining the value of an unknown mass using the resonant frequencies of known masses on a spring

8.1 Equipment

- Spring ($21.5Nm^-1$)
- Slotted masses and hanger
- Retort stand with bosses and clamps
- Signal generator
- Plasticine
- Mass scale
- Oscillator

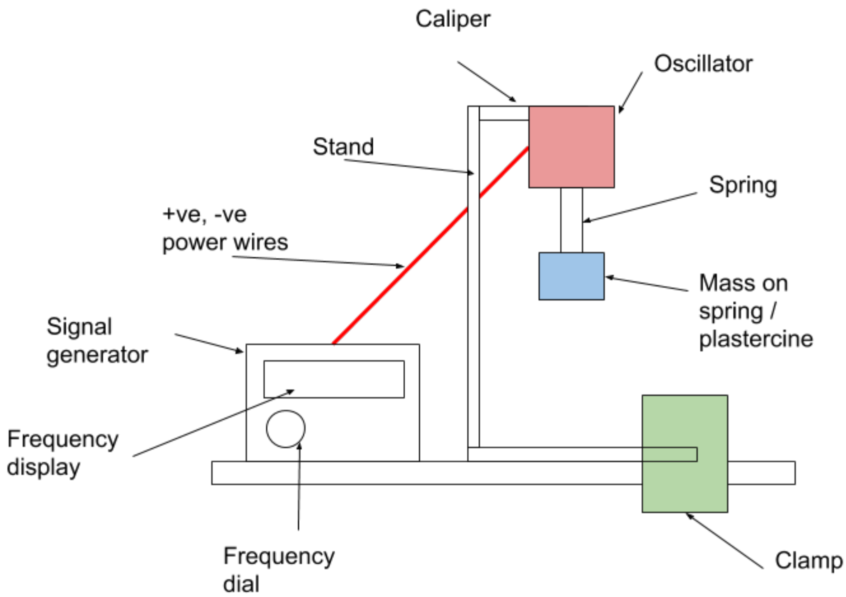


Figure 10: Labelled diagram

8.2 Method

- Build set-up, shown in Figure 10.
- When the mass on the spring (the oscillating system) experiences a driving force at the same frequency as its natural frequency, the system takes in energy from the driving force.
- Taking in this energy increases the systems amplitude. From Hooke's law we known that $F \propto \Delta x$, where x is the displacement from equilibrium position - the amplitude of oscillation.
- By tweaking the signal generator to control the frequency of the oscillator, we can induce resonance and thus find the resonant frequency of the mass on a spring.
- The natural frequency should be recorded as the frequency at which the mass on the spring has the greatest amplitude.
- Add a 10g mass to the spring

- Find the new resonant frequency and thus the natural frequency also.
- Repeat up to 150g
- Draw a line of best fit and calculate its equation.
- Add a piece of plastercine of unknown mass to a 50g mass on spring
- Change the signal generators output until the resonant frequency of the system is found
- Using this frequency, the natural frequency, calculate it's mass from the following equations:

$$T = 2\pi\sqrt{\frac{m}{k}} \tag{65}$$

$$m = k\left(\frac{T}{2\pi}\right)^2 \tag{66}$$

8.2.1 Control Variables

- Same spring
- Constant amplitude of oscillation for the oscillator

8.2.2 Risk Assessment

- Protective glasses should be worn to avoid spring from entering eye
- Stand should be clamped to the work table to prevent it from falling over

8.3 Results

Mass (g)	Natural Frequency (Hz)
50	3.11
60	2.91
70	2.79
80	2.53
90	2.38
100	2.28
110	2.20
120	2.11
130	2.02
140	1.91
150	1.74

Table 8: Natural frequencies of known masses

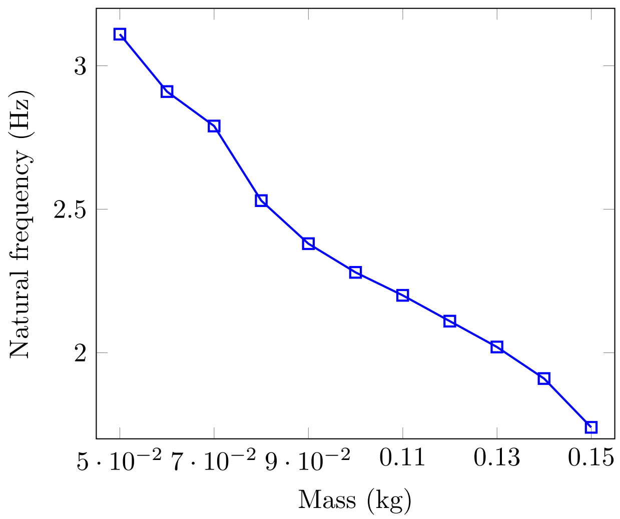


Figure 11: Natural frequency against mass

8.3.1 Calculating the unknown mass

The mass of Plasticine was measured as $18.9g$.
The natural frequency was measured as $2.81Hz$.

$$m = k\left(\frac{T}{2\pi}\right)^2 \tag{67}$$

$$m = 21.5\left(\frac{\left(\frac{1}{2.81}\right)}{2\pi}\right)^2 \tag{68}$$

$$m = 68.6g \tag{69}$$

$$m = m - 50 \Rightarrow 18.6g \approx 18.9g \tag{70}$$

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9.1 Acknowledgements

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