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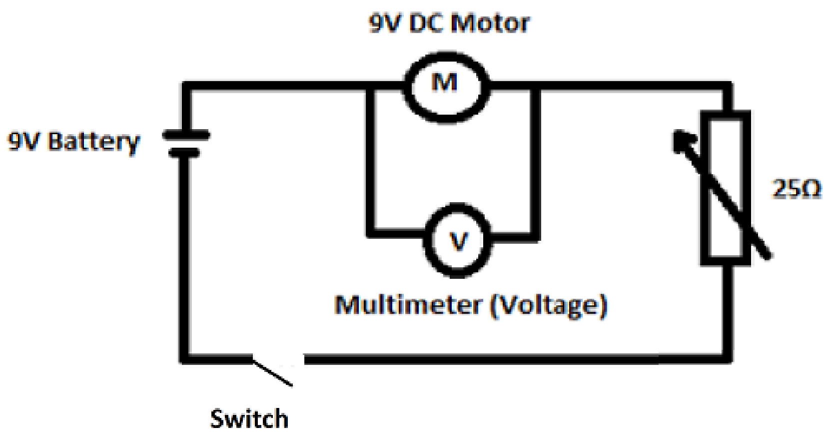
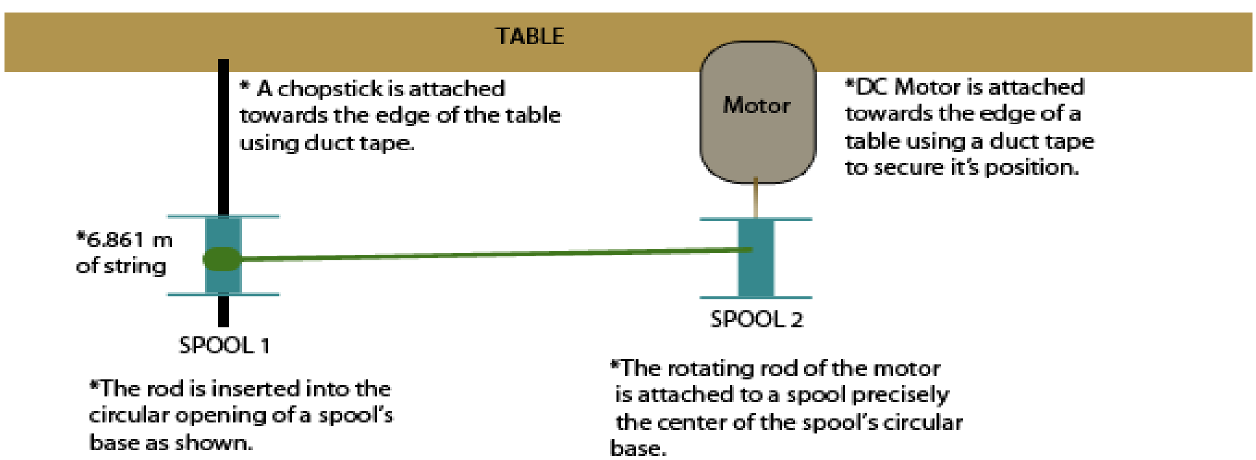
**IB Physics SL Internal Assessment**

**Research Question:** How does the voltage supplied to an electric motor affect its spin rate?

The purpose of this experiment is to investigate the effect of the voltage supplied on the spin rate of a 9V DC electric motor. The independent variable is the Voltage supplied to the motor, and will be measured using a multimeter (voltage). A variable resistor with a maximum resistance of 25 Ω will be used to control the voltage supplied to the motor. The circuit diagram below shows the setup for controlling voltage:




The dependent variable is the motor's spin rate. The following arrangement is set up to calculate the spin rate:




* One end point of the string is attached to spool 1 and the 6.8612 m string is coiled completely around spool 1. The other endpoint of the string is then attached to spool 2. Spool 1 is rotated counterclockwise to tighten the string.

In a desired condition of voltage, the motor spins spool 2 which causes the string to coil around the spool 2 and to uncoil from spool 1. A stop watch is used to measure the time it takes for the string to completely uncoil from Spool 1 in seconds. The length of the string coiled on spool 2 is: $string\ length - distance\ between\ the\ spools$ = 6.8612 m - 0.2000 m = 6.6612 m. The diameter of the spool 2's cylindrical body where the string coils is 0.0260 m. The spin rate in rotations per minute is calculated using this formula: $Spin\ rate = \frac{number\ of\ coils}{time} =$

$$\frac{Coiled\ string's\ length}{circumference\ of\ each\ coil\ \times time(s)} \times 60 = \frac{6.6612 \times 60}{0.026\,\pi \times time(s)}$$

The five conditions of voltage in this experiment are 7.05V, 7.47V, 7.89V, 8.31V and 8.73V. One trial of this experiment is conducted by holding spool 2 so that it cannot move, connecting the 9V battery to the circuit, turning on the switch, and starting the stop watch when spool 2 is released. The stop watch is stopped when the spools stop moving after all the string that can be coiled has been coiled around spool 2. Five trials will be conducted for each voltage condition, for a total of 25 trials. Some constants to maintain across all trials and conditions are: the length of the string, masses of the two spools, circumferences of the two spools, the power supply of the entire circuit, the distance between two spools, the length of the chopstick, the shape of the rod where spool 1 is inserted.

My hypothesis is that as the voltage increases, the spin rate increases as well, since higher voltage will drive a greater flow of current. The greater flow of electrons will lead to a greater amount of power output, thus increasing spin rate of the motor.

**Table of Variables:**

| **Variable Name** | **Type** | **Method of Control** |
|---|---|---|
| Voltage supplied to the motor | Independent | A multimeter connected in parallel with the motor is used to get a measure of the voltage supplied to the motor. A variable resistor of the maximum resistance of 25Ω is used in the circuit to alter the voltage supplied to the motor. The variable resistor is then adjusted to varying resistance corresponding to these voltage readings shown by the multimeter: 7.05 V, 7.47 V, 7.89V, 8.31 V and 8.73 V. |
| Spin rate of the motor | Dependent | The spin rate is determined by using a stopwatch with a precision of +/- 0.01s to measure the time it takes for all the string |

| | | |
|---|---|---|
| | | (6.6612m in length) to uncoil from spool 1. The spin rate in rpm is then calculated using the following formula: $spin\ rate = \frac{6.6612 \times 60}{0.026\,\pi \times time\ from\ stop\ watch}$ |
| Length of the String | Constant | A meterstick with a precision of +/- 0.00005m is used to measure the length of the string used to be 6.8612 m. |
| Distance between the two spools | Constant | A meterstick with a precision of +/- 0.00005m is used to measure the distance between the two spools to be 0.2000 m. |
| Mass of spool 1 and spool 2 | Constant | The mass of spool 1 and the mass of spool 2 are both determined to be 25.23 g by using an electronic scale with a precision of +/- 0.01 g. |
| Circumference of the cylindrical body (where the string coils) of spool 1 and that of spool 2 | Constant | A meterstick with a precision of +/- 0.00005m is used to measure the diameter of spool 1 and diameter of spool 2 to be 0.0262m each. |
| Height of the cylindrical body (where the string coils) of spool 1 and that of spool 2 | Constant | A meterstick with a precision of +/- 0.00005m is used to measure that the height of spool 1 and the height of spool 2 are both 0.0554 cm. |
| Alignment of spool 1 relative to spool 2 | Constant | A meterstick with a precision of +/- 0.00005m is used to ensure that both spool 1 and spool 2 are 0.0500m away from the edge of the table in the horizontal direction. |
| Total Voltage supplied to the circuit | Constant | A 9V Battery is used for all trials and conditions. The labeling on the battery itself is checked to ensure that it creates a potential difference of 9V. |
| Length of the cylindrical rod (chopstick) upon which spool 1 is inserted | Constant | A meterstick with a precision of +/- 0.00005m is used to measure the length of the chopstick to be 0.2030 m. |
| Shape of the chopstick | Constant | To allow for spool 1 to rotate consistently, the chopstick is |

| | | |
|---|---|---|
| | | checked to have a round profile. This is done by rolling the chopstick across a flat surface, and observing that it rolls along the surface with a seemingly consistent rolling motion; without any noticeable oscillations of speed. |
| Alignment of the motor and the chopstick with respect to the table | Constant | A protractor with a precision of +/- 0.5° is used to unsure that the motor and chopstick both make a 90° angle with both the horizontal edge and the vertical edge of the rectangular prism that is the table's flat roof. |
| Direction of the motor's spin | Constant | It was observed that in the circuit, when the end point of the wire from the motor was connected to the positive terminal of the battery, the motor spins in a clockwise direction. This clockwise direction is controlled by ensuring that the end point of the wire from the motor is connected to the positive terminal of the battery, and the end point of the wire from the switch is connected to the negative terminal of the battery. |
| Time between trials | Constant | It was observed that the motor heats up after some usage. In order to minimize the effect of heat on the circuit, a stopwatch with a precision of +/- 0.01s will be used to ensure that the circuit will be switched off for 120.0s between trials. |

**Materials:**

1) 9V DC Motor
2) 25Ω variable resistor
3) Copper wire
4) Multimeter
5) 6.8612 m of white cotton string of medium length
6) A wooden chopstick with round profile
7) Stopwatch with precision of +/- 0.01s
8) 2 identical spools
9) Duct tape
10) Table with flat surface
11) Scale to measure mass
12) Meter stick with precision of +/- 0.00005m
13) Liquid super glue
14) Scissor
15) Cardboard

**Protocol Diagram:**

**Circuit:**

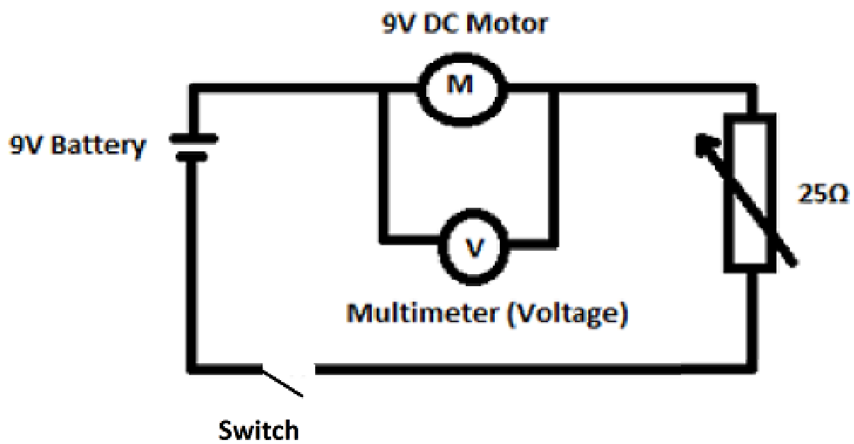
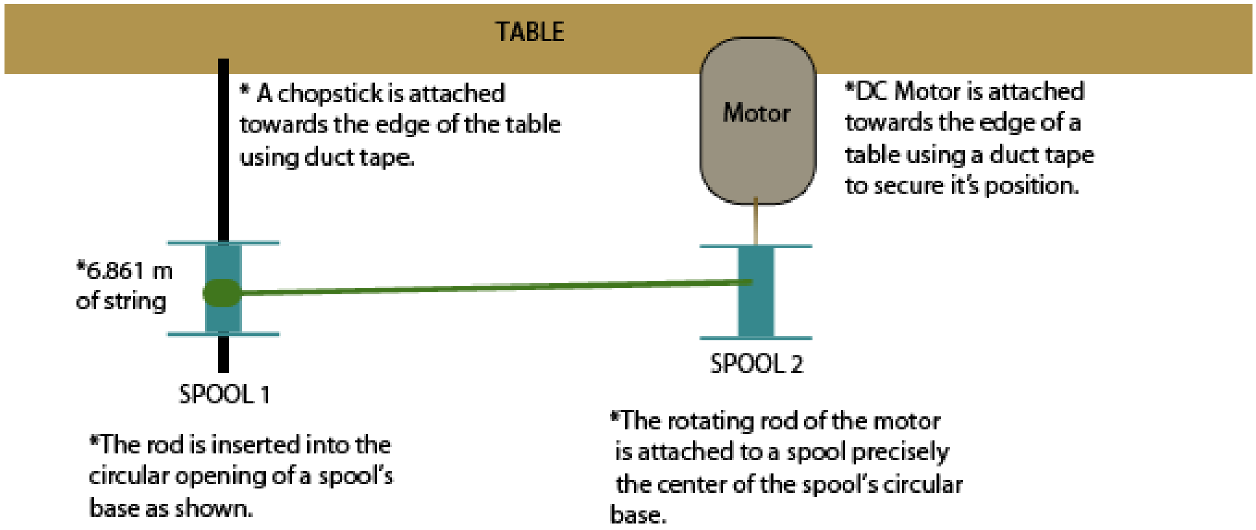


**Table Setup:**

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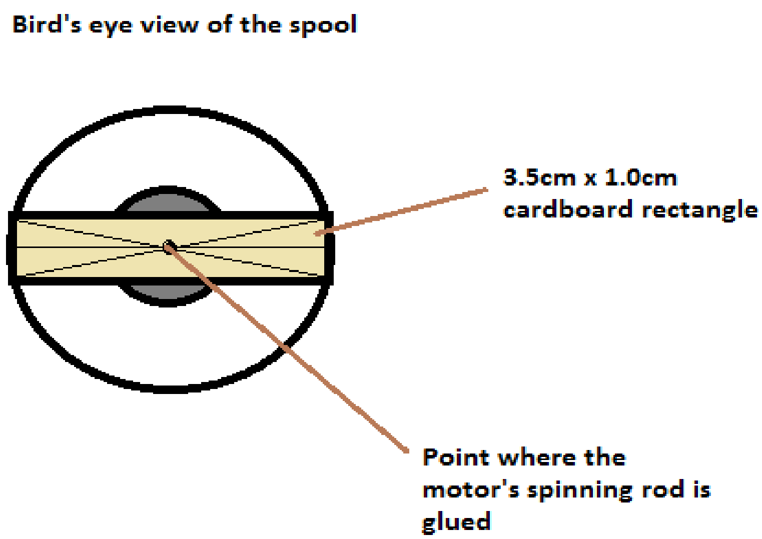
**Motor and Spool 2 system:**



## Procedure:

**A) Preparation of the motor and the spool 2 system:**

**1)** Cut out a rectangle of the dimensions 3.5 cm by 1.0 cm from a piece of cardboard.
**2)** Using a pencil and a straight edge, trace the two diagonal lines of the rectangle.
**3)** Find the point of intersection of the two diagonals of the rectangle.
**4)** Using a ruler and a pencil, draw a straight line across the rectangle from 0.5 cm of the width (midpoint of the width).
**5)** Drop liquid superglue around the perimeter of the rectangle.
**6)** Since the diameter of the circular base of spool 2 is 3.5 cm, place the rectangle on top of the circular base such that the rectangle's length (3.5cm) at the midpoint of its width, fits within the boundary of the circular base.
**7)** Wait until the superglue is dried, and the rectangle should now be secured in its position.
**8)** Use a needle to poke a narrow hole through the point of intersection of the diagonals.
**9)** Insert the motor's spin rod into this hole, and use a protractor to insure that the motor is 90° from the surface of the rectangle.
**10)** While holding the motor in this position, drop liquid superglue from the top of the motor's spin rod so that it binds the spinning rod to the cardboard rectangle, and therefore, to the spool.
**11)** Wait until the superglue is dried and the motor's position is secured.

**B) Preparation of the circuit:**

**1)** Using the copper wire, connect the motor in series with the variable resistor and the switch.
**2)** Connect the multimeter in parallel with the motor and select the voltage measurement option.
**3)** Connect the endpoint of wire from the motor to the positive terminal of the 9V battery and the endpoint of the wire from the switch to the negative terminal of the 9V battery.

**C) Preparation of the table set up:**

**1)** Use a ruler to place the motor on the edge of the table such that the tip of the motor is 3.0 cm away from the edge of the table.
**2)** Use the duct tape to secure the placement of the motor on the edge of the table.
**3)** Use a ruler to place the chop stick 20.0 cm from the motor on the table edge.
**4)** Use the duct tape to secure the placement of the chopstick on the edge of the table, leaving only 5.0 cm of chopstick to be in direct contact with the table.
**5)** Use a protractor to ensure that the motor and the chopstick make a 90° angle with the horizontal edge of the table. Adjust the position of the motor and the chopstick so that they do not deviate from this arrangement.

**6)** Use the protractor to ensure that the motor and the chopstick make a 90° angle with the vertical edge of the table. Adjust the position of the motor and the chopstick so that they do not deviate from this arrangement.

**D) Arrangement of the string and spools:**

**1)** Use the superglue to attach one end of the string to spool 1 and wait until the glue is dried.
**2)** Coil all the string around spool 1.
**3)** Use the superglue to attach the other end of the string to spool 2 and wait until the glue is dried.
**4)** Use a ruler to ensure that spool 1 is 3.0 cm away from the edge of the table. It should align with spool 2, which is also 3.0 cm away from the edge of the table.
**5)** Rotate spool 1 counterclockwise so as to tighten the string.

**E) Steps in running the trials:**

**1)** Hold spool 2 to immobilize it.
**2)** Turn on the switch and adjust the variable resistor so that the multimeter shows a reading of 7.05V.
**3)** Let go of spool 2 and turn on the stopwatch simultaneously.
**4)** Measure the time it takes for both the spools to stop moving after all the string has been uncoiled from spool 1.
**5)** Record this time.
**6)** Turn off the switch.
**7)** Use the stopwatch to wait for 120.0 s. During this time, rotate spool 1 counterclockwise so that the string is completely uncoiled from spool 2 and coiled around spool 1.
**8)** Repeat steps 1-7 four more times for this condition of voltage.
**9)** Repeat steps 1-8 four more times, adjusting the voltage in step 2 to be 0.42V greater than the voltage condition right before.

## Raw Data:

| **Table 1:** The effect of Voltage on the time required by the motor to coil all the string | | | | | | | |
|---|---|---|---|---|---|---|---|
| Voltage (V) | Time required by the motor to coil all the string (s) (+/- 0.01 s) | | | | | | |
| | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Mean | Half Range |
| 7.05 | 9.28 | 9.03 | 9.15 | 8.89 | 7.95 | 8.86 | 0.67 |
| 7.47 | 9.01 | 8.60 | 8.55 | 7.97 | 7.71 | 8.37 | 0.65 |
| 7.89 | 6.81 | 7.11 | 7.14 | 7.85 | 6.96 | 7.17 | 0.52 |
| 8.31 | 5.25 | 5.92 | 6.13 | 6.28 | 6.01 | 5.92 | 0.52 |
| 8.73 | 4.58 | 5.85 | 5.79 | 5.86 | 5.78 | 5.57 | 0.64 |

## Sample Calculations:

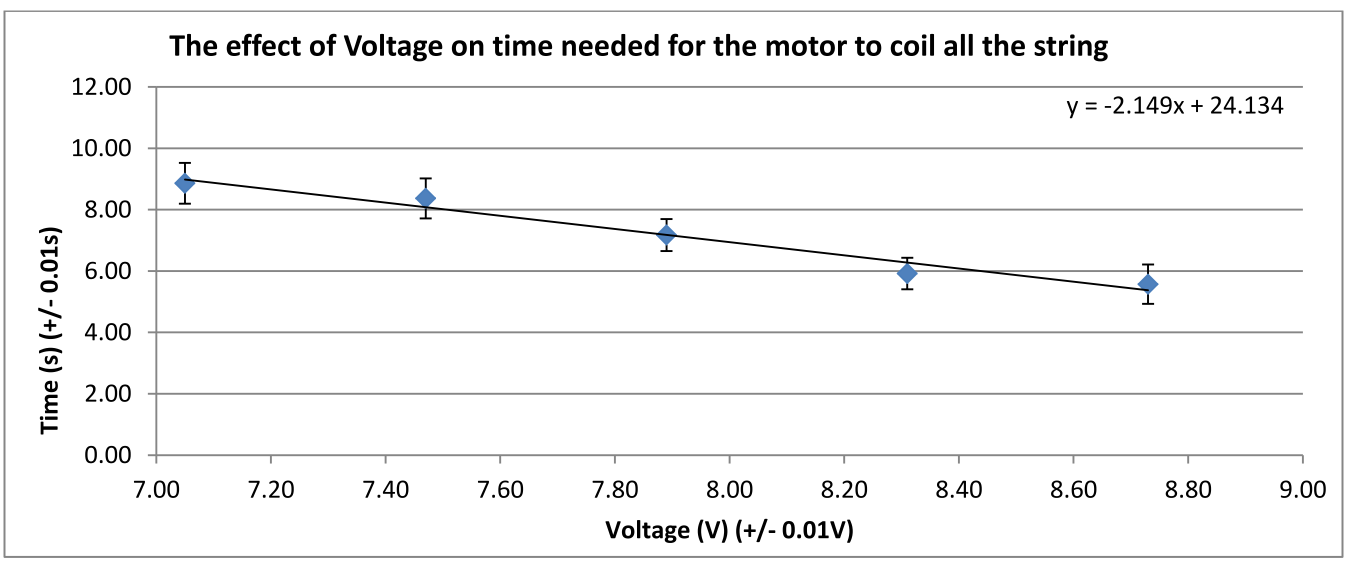
- $$Mean = \frac{sum\ of\ data\ values}{number\ of\ data\ values}$$

$$7.05V\ condition: Mean = \frac{(9.28s + 9.03s + 9.15s + 8.89s + 7.95s)}{5} = 8.86s$$

- $$Half\ Range = \frac{Max - Min}{2}$$

$$7.05V\ condition: Half\ Range = \frac{(9.28 - 7.95)}{2} = 0.67s$$

## Raw Data Graph:



**Qualitative Data:**

1) The cardboard rectangle used to attach to spool was too flimsy, and it led spool 2 to wobble slightly for trial 2 of 7.05V condition. The cardboard was therefore, replaced with a wooden rectangle of the same dimensions for the rest of the trials.
2) There was no noticeable wobbling motion of spool 2 for all trials when the wooden rectangle was used.

**Processed Data:**

| The effect of Voltage on the rate of spin of the motor | | |
|---|---|---|
| Voltage (V) | Mean Spin Rate (rpm) ($min^{-1}$) | Half Range of Mean Spin Rate (rpm) ($min^{-1}$) |
| 7.05 | 552.53 | 88.25 |
| 7.47 | 585.01 | 91.61 |
| 7.89 | 682.38 | 95.24 |
| 8.31 | 827.20 | 152.93 |
| 8.73 | 878.57 | 233.47 |

**Sample Calculations:**

- $Mean\ Spin\ Rate = \frac{number\ of\ coils}{Mean\ time} \times 60 =$

$$\frac{Coiled\ string's\ length}{circumference\ of\ each\ coil\ \times\ Mean\ time} \times 60 = \frac{6.6612\ m\ \times 60}{0.0260\ \pi\ \times\ Mean\ time} =$$

7.05 V condition: $Mean\ spin\ rate =$

$$\frac{6.6612\ \times 60}{0.0260\ \pi\ \times\ 8.86} = 552.53\ \mathrm{min}^{-1}$$

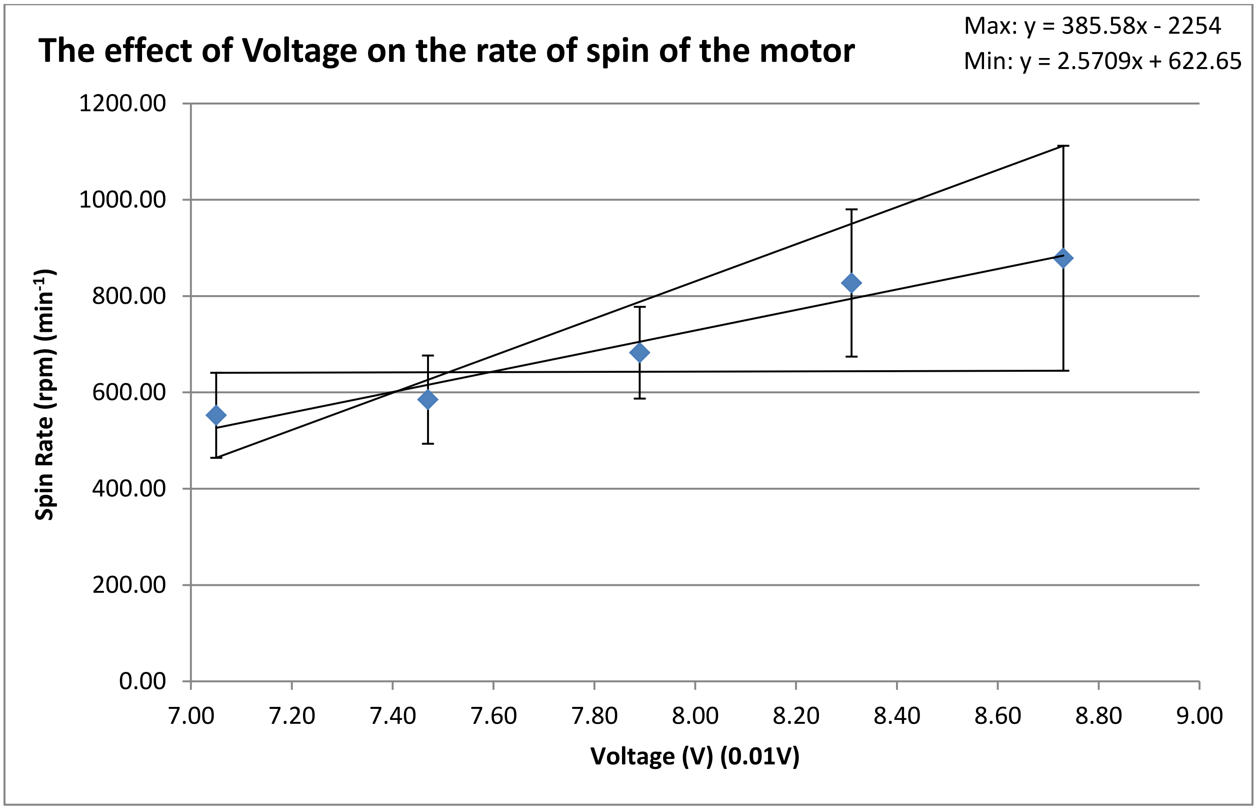
- $Half\ Range\ of\ Mean\ Spin\ rate =$

$$\frac{\left(\frac{6.6612\ \times 60}{0.0260\ \pi\ \times\ Min\ time}\right) - \left(\frac{6.6612\ \times 60}{0.0260\ \pi\ \times\ Max\ time}\right)}{2}$$

7.05 V condition: $Half\ Range\ of\ Mean\ Spin\ rate =$

$$\frac{\left(\frac{6.6612 \times 60}{0.0260\,\pi \times 7.95}\right) - \left(\frac{6.6612 \times 60}{0.0260\,\pi \times 9.28}\right)}{2} = 88.25 \text{ min}^{-1}$$

**Processed Data Graph:**




In the graph above, trend line with the maximum and the minimum slope, along with the average slope are shown.

**Calculations:**

- $Units\ of\ slope = \frac{\Delta y}{\Delta x} = \frac{min^{-1}}{V} = min^{-1}V^{-1}$

- <u>Max line of best fit:</u>

$$slope = \frac{(min\ spin\ rate\ at\ 7.05V) - \ (max\ spin\ rate\ at\ 8.73V)}{\Delta x}$$

$$Min\ spin\ rate = (Mean\ spin\ rate - Half\ Range)$$
$$Max\ spin\ rate = (Mean\ spin\ rate + Half\ Range)$$

$$\frac{(552.53 - 88.25) - \ (878.57 + 233.47)}{(7.05 - 8.73)} = 385.57\ min^{-1}V^{-1}$$

Equation from graph: y = 385.58x -2254. The slight variation in calculated slope and excel's slope is because excel has more precise calculating ways.

- <u>Min Line of best fit:</u>

$$Min\ slope = \frac{(max\ spin\ rate\ at\ 7.05V) - \ (min\ spin\ rate\ at\ 8.73V)}{\Delta x}$$

$$Min\ spin\ rate = (Mean\ spin\ rate - Half\ Range)$$
$$Max\ spin\ rate = (Mean\ spin\ rate + Half\ Range)$$

$$\frac{(552.58 + 88.25) - \ (878.57 - 233.47)}{(7.05 - 8.73)} = 2.5714\ min^{-1}V^{-1}$$

Equation from the graph: y = 2.5709x + 622.65. The slight variation in calculated slope and excel's slope is because excel has more precise calculating ways.

- $Slope\ and\ uncertainty =$
  $Average\ of\ Min\ slope\ and\ Max\ slope\ \pm\ Half\ range\ of$ min $and$ max $slopes$

$$\frac{385.58+2.5709}{2} \pm \frac{385.58-2.5709}{2}$$
$$= 194.08\ min^{-1}V^{-1} \pm 191.50\ min^{-1}V^{-1}$$

The unit of the slope is $min^{-1}V^{-1}$. From the calculations and the graph, the slope of the trend line is$194.08\ min^{-1}V^{-1} \pm 191.50\ min^{-1}V^{-1}$.

**Conclusion and Evaluation:**

The graphs show a positive linear relationship between voltage and spin rate. Averaging the slopes of the max min line and the y-intercepts of the max and min line, the equation for the relationship $y = 194.08x - 815.7$ was attained. This suggests that voltage is not proportional to spin rate. Using the graph to forecast, at some condition of voltage below 7.05V but greater than 0.00V, the motor will not spin. Therefore, it is suggestive of a threshold voltage for there to be a spin.

I am confident in the quality of my data to a moderate extent. Although the uncertainty of the slope is very high; $194.08\ min^{-1}V^{-1} \pm 191.50\ min^{-1}V^{-1}$, I am confident in the positive relationship between voltage and spin rate. This is because the least possible slope is 2.5709 $min^{-1}V^{-1}$, which, although close to zero, is positive. However, the data value themselves of spin rate had large error bars. The smallest error bar was $(\frac{88.25}{552.53}) \approx 20\%$ of the data value, while the largest error bar was $(\frac{233.47}{878.57}) \approx 26\%$ of the data value. Moreover, almost all the error bars are overlapping. Although this level of uncertainty can show the general trend of the relationship, it is not precise enough to access the exact nature of relationship with certainty.

One design flaw was that the voltage conditions used were not sufficiently different from one another. The small change in voltage between conditions led to a small change in the spin rate, thus, making it difficult to detect these small changes. For example, for trial 5 of 7.05V, the time recorded was 7.95s, while time for trial 4 of 7.47V was 7.97s. The difference here is 0.02 s. It demonstrates that potentially, the difference in spin rate could be as tiny as being about 0.02s, which is much too small for a human using a stopwatch with a precision of +/- 0.01s to detect with consistent accuracy. This resulted in large error bars that were almost always overlapping. A data suggestive of a clearer relationship could have been achieved if the voltage conditions were more spread out. My suggested improvement would be to use the voltage conditions of 3.0V, 6.0V, 9.0V, 12.0V, 15.0V. A 3.0V difference between conditions should be enough to spin the spool at more noticeably different rates. This, however, would also require at least a 15.0V battery, and a 15 V DC motor.

Another source of error was that the time was measured by a human using a stopwatch. Human perception has a lag time of 0.1s,[1] and the responses from the muscles to stop the

[1] Nielson, Jackob. "Response Times: The 3 Important Limits". Article. Nielsen Norman Group. January 1, 1993. Web. <http://www.nngroup.com/articles/response-times-3-important-limits/>

stop watch would take some more time that can vary from one trial to the other. Human visual perception was not a reliable way to measure time for this experiment, especially since the changes in time due to voltage were very small. This could have greatly affected the accuracy and the consistency of my data. My suggested improvement would be to record the experiment using a slow motion camera, and using a video player on a capable computer to pinpoint the time when the spool started moving, and the time when the spool stopped moving, and the using their difference to calculate for the time to record as a data value. This eliminates human errors concerning time measurement with stopwatch.