What effect does a mass hanging on one side of a nichrome wire (1050g,1250g,1450g,1650g,1850g/±0.1g) have on the frequency of harmonics (Hz, ±0.1Hz) with the length 0.4(m) and the same cross section (m^2) for the same density (g/cm^3)?

IB Physics IA

Background:

This study aims to explore the relationship between the mass hanging on one side of a nichrome wire and its harmonic fundamental frequency of a closed-closed standing wave. Standing wave are formed if there is a specific frequency on the string.This study will analyze how changes in hanging mass affect harmonic fundamental frequency and systematically adjust the tension of the same nichrome wire by controlling the weights that the string is subjected to. The choice of nichrome wires as the subject of this investigation is due to their characteristic vibration at specific frequencies when tightened and released. However, the specific density of nichrome wire used in this study will be calculated through the experiment. Additionally, because nichrome wires are fixed at two ends and free to vibrate in the middle, they undergo single harmonic motion. In this study, the tension is the weight hanging on one side of the nichrome wire.

Deriving the relationship between the mass hanging on one side of the nichrome wire as tension and frequency of harmonics:

Table 1 below lists the variables used in the formula derivations:

Variables	Meaning	Unit
v	Wave speed	ms^{-1}
λ	Wavelength of nichrome wire harmonics	m
f	Frequency of nichrome wire harmonics	Hertz (Hz)
L	Nichrome wire length	m
F	Tension of nichrome wire	N
μ	Linear density of nichrome wire	kgm^{-1}
ρ	Density of nichrome wire	kgm^3
m	Mass of nichrome wire	kg
V	Volume of nichrome wire	m^3
A	Cross-section area of nichrome wire	m^2
M	the mass hanging on one side of the nichrome wire	kg

Table.1 The variables used in the formula derivation.

The wavelength, λ, frequency of harmonics, f, time period, T, and wave speed, v, applied to wave motion is given by:

$$v = \lambda f$$

Furthermore, in the context of string vibrations, it is imperative to note that for the fundamental harmonic on a string, the wavelength precisely equals twice the length of the string:

$$\lambda = 2L$$

So, replacing wavelength, λ, with string length, L, yields:

$$v = 2Lf$$

However, this derivation does not establish the relationship between the tension, T and frequency, f. Therefore, based on the definition of the wave speed as the velocity at which the waves propagate in a medium, in the context of wave propagation along a string, the string itself acts as the medium. Hence, the wave speed, v can also be expressed as:

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

For the sake of practical measurement, this investigation transforms the linear density parameter, μ, denoting the mass per unit length of an object, into the product of the cross-sectional area, A, and the density, ρ. This conversion is derived from the definition of volume density, ρ, commencing with:

$$\rho = \frac{m}{V}$$

For a one-dimensional object, such as a nichrome wire, its volume can be expressed as the product of the cross-sectional area, A, and the length, L:

$$V = A \times L$$

Therefore, substituting the definition of volume density, ρ, yields:

$$\rho = \frac{m}{A \times L}$$

Rearranging the above equation yields the definition formula for linear density, μ:

$$\mu = A \times \rho$$

Equating this expression with the formula represented by the wave speed, *v*:

$$\sqrt{\frac{F}{A \times \rho}} = 2Lf$$
$$\Rightarrow F = (2Lf)^2 A\rho$$

Through rearrangement, the relationship between *f,* and *M* can be established:

$$f = \frac{1}{2L}\sqrt{\frac{F}{A\rho}}$$

Determine the relationship between frequency, *f* and tension, *F:*

$$f^2 = \frac{1}{4L^2 A\rho} F$$

From the equation, it could be deduced that plotting the f^2, against tension *F* will create a linear curve, because:

$$f \propto \sqrt{c}\sqrt{F}$$

Where c is the constant in the study, and $\sqrt{c} = \sqrt{\frac{1}{4L^2 A\rho}}$, because the variables in the formula are constant, where $L = 0.400m$, $A = \pi r^2 = \pi\ (3\times 10^{-4})^2 = 9\times 10^{-8} m^2$, the nichrome wire's ρ is approximately $8400kgm^{-3}$, but the specific ρ will be determined by the experiment.

Hypothesis:

From the derived formula, it could be hypothesized that as the mass hanging on one side of the nichrome wire as tension (F) of nichrome wire increases, the frequency (Hz) of harmonics detected when strumming the nichrome wire will increases. Also, *f* is proportional to *F* to the power of 0.5.

Methodology:

Table 2 below lists the independent variable and dependent variable in the experiment:

Variables	Details
Independent	The mass hanging on one side of the nichrome wire as the tension (1050g, 1250g, 1450g, 1650g, 1850g/±0.1g). This will be accomplished by using weights to manipulate.
Dependent	The frequency of harmonics of the nichrome wire measured by the phone app Tunable (± 0.1 Hz, see Apparatus list in the later part) .

Table 2. The independent variable and dependent variable.

Image 1 below shows the icon of the app I used called Tunable:

Image 1. The con of the app I used.

Image 2 below shows the page interface of the app I used called Tunable:

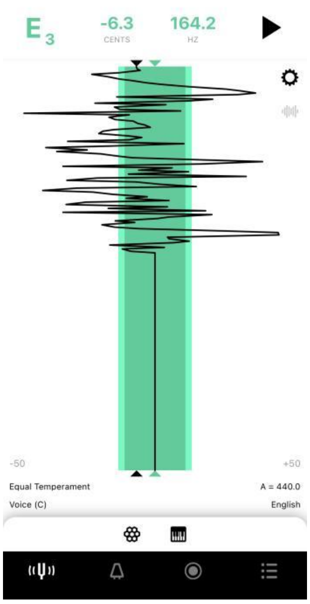

Image 2. The page interface of the app I used called Tunable.

Table 3 below lists the control variables in the experiment:

Control variables	Why and how to control the variable
Length of the nichrome wire	According to the formula, the length of the nichrome wire affects the frequency. It must be controlled so that the change of frequency is solely due to the change of tension of nichrome wire. The length of the nichrome wire will be kept constant by using the same nichrome wire throughout the experiment.
Cross-section area of the nichrome wire	According to the formula, the cross-section area of the nichrome wire also affects the frequency. It will be controlled by using the same object with the same cross-section area throughout the experiment.
Density of the nichrome wire	According to the formula, the density of the nichrome wire also affects the frequency. It must be controlled so that the change of frequency is solely due to the change of tension of nichrome wire. The density of the nichrome wire will be kept constant by always using the same mass and volume with the same material nichrome wire

Table 3. Control variables.

Note that there are some methodological strategies to be applied to the upcoming procedure. First, as the frequency of sound will be detected by the phone app, the experiment will be performed in a quiet room with constant and low ambient sound. Second, the act of plucking the nichrome wire can introduce variations in tension. Therefore, verifying the tension before each experimental trial is crucial to minimize the potential for random error.

Apparatus:

Table 4 below lists the apparatus in the experiment:

Apparatus	Quantity	uncertainty
Nichrome wire	1	/
Weight used on a balance	n	±0.1 g
App (Tunable) to test frequency	1	± 0.1 Hz
Pulley	1	/
Hook	1	/
Ruler	1	±0.0005m
Timber pile	2	/

Table 4. Apparatus list.

Set up:

Figure 1 below shows the in the experimental set up:

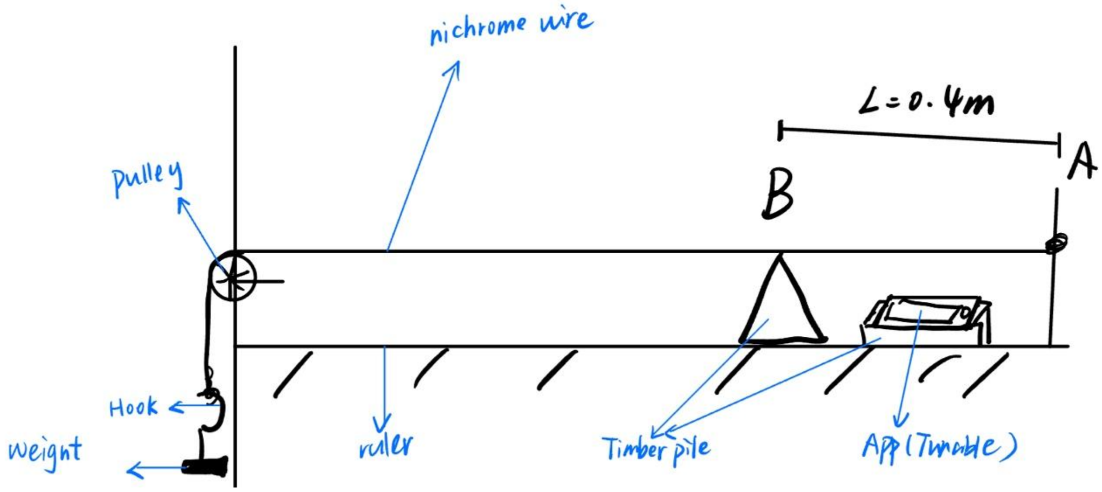

Figure 1 the set-up apparatus

Procedure:
1: Set up the experiment as seen in Figure 6. Tie the nichrome wire to an apparatus, and use the distance between points A and B as the length of the wire in the formula.
2: Measure the weights (1050g), hanging from the nichrome wire.
3: Open the phone app Tunable. Pluck the nichrome wire with hand lightly in the length of the wire. Measure the frequency (Hz) and record the data on the data table.
4: Repeat steps 1, 2, and 3 five times with more than three concordant results.
5: Repeat steps 1-4 for (1050g,1250g,1450g,1650g,1850g) weights, respectively.

Safety, environmental and ethical concerns:

As multiple experiments are conducted and tension increases over time, the nichrome wire may become excessively tight, leading to situations where it snaps and potentially causes injuries to individuals involved.

Raw data

Qualitative Data:
When a nichrome wire is vibrated, it initially produces a sound which gradually fades until it becomes inaudible. As the mass hanging from the wire increases, thereby increasing the tension, the frequency of the sound detected by Tunable arises. Simultaneously, the sound transitions from a deeper tone to a crisper one.

Quantitative Data – Raw Data Table
Table 5 below shows the raw data table:

Trial #	The mass (g) hanging on one side of the nichrome wire (±0.1g)	The frequency (Hz) of harmonics of the nichrome wire (±0.1Hz)
1	1050.0	76.0

2		75.8
3		75.8
4		76.2
5		75.9
1	1250.0	82.8
2		82.5
3		83.2
4		83.1
5		82.5
1	1450.0	89.2
2		88.4
3		89.0
4		88.6
5		89.5
1	1650.0	96.0
2		95.7
3		96.1
4		95.8
5		95.5
1	1850.0	102.1
2		101.3
3		101.0
4		101.9
5		101.8

Table 5. The raw data table of the hanging mass and the frequency of the nichrome wire.

Sample calculation

In my investigation, the tension is defined as:

$$\sqrt{\text{the hanging mass} \times \text{gravitational acceleration}}$$

A sample calculation is based on hanging mass of 1050g is given below:

$$\text{Tension}(F) = \sqrt{\text{the hanging mass}(M) \times \text{gravitational acceleration}(g)}$$

$$= \sqrt{1050\text{g} \times 9.81\text{ms}^{-2}} = \sqrt{1.05\text{kg} \times 9.81\text{ms}^{-2}} = 3.21\text{N}$$

$$\frac{\Delta F}{F} = 0.5\frac{\Delta M}{M} + 0 = 0.5 \times \frac{0.100}{1050} = 4.76 \times 10^{-5}$$

$$\frac{\Delta F}{F}F = 4.76 \times 10^{-5} \times 3.21 = 0.000153 \approx 0.0002$$

$$\Delta F = 0.02\%$$

The average value of the frequency of harmonics of the nichrome wire:

$$\text{frequency (Hz)} = \frac{76.0 + 75.8 + 75.8 + 76.2 + 75.9}{5} = 75.9\text{Hz}$$

The uncertainty of the frequency is estimated using half range method:

$$f = \frac{\text{MAX}(f) - \text{MIN}(f)}{2} = \frac{76.2 - 75.8}{2} = 0.2 \text{ Hz}$$

Following a similar procedure, the data for other values of hanging mass will be processed. The processed data is then summarized in Table 6 below:

Tension of the nichrome wire (F) ±0.02%	Average frequency (Hz)	Uncertainty of frequency
3.21	75.9	0.2
3.50	82.8	0.4
3.77	88.9	0.6
4.02	95.8	0.3
4.26	101.6	0.6

Table 6. Tension of the nichrome wire vs. Frequency.

*Uncertainty of frequency is kept as one significant figure.

*The average frequency is adjusted according to the significant figure in its uncertainty

Figure 2 below shows the Frequency VS Tension of the nichrome wire with uncertainties:

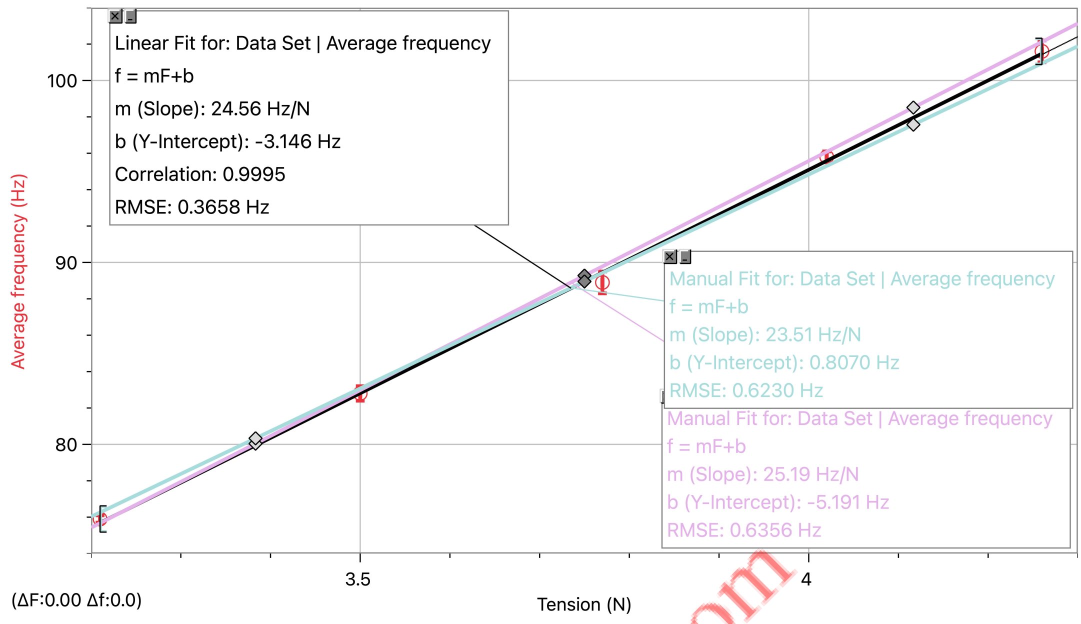

Figure 2 Frequency (Hz) VS Tension of the nichrome wire with uncertainties.

The best fit line reveals a relationship:

$$\mathrm{f} = 24.56\mathrm{Hz} - 3.146\mathrm{Hz}$$

The worst fit line reveals a relationship:

$$\mathrm{f} = 25.19\mathrm{Hz} - 5.191\mathrm{Hz}, \mathrm{f} = 23.51\mathrm{Hz} + 0.8070\mathrm{Hz}$$

The uncertainty of the gradient is:

$$\frac{25.19\mathrm{Hz} - 23.51\mathrm{Hz}}{2} = 0.8\mathrm{Hz}$$

The uncertainty of the Y-Intercept is:

$$\frac{0.8070 - (-5.191)}{2} = 2.99 = 3\mathrm{Hz}$$

Therefore,

$$f = (24.6 \ \pm 0.8)\sqrt{F} - (3 \pm 3)\mathrm{Hz}$$

Conclusion:

The purpose of this investigation was to calculate the effect of the change in mass (kg) on one side of the wire as tension (N) on the harmonics frequency (Hz) by performing an experiment and also determine the coefficient of the square root of the tension of the wire nichrome so that the material's density can be determined. It was hypothesized that there is a linear relationship between the square root of the tension and the harmonics frequency.

The experimental data was plotted and revealed a relationship as $f = (24.6 \pm 0.8)\sqrt{F} - (3 \pm 3)\text{Hz}$ and it indicated that when the square root of tension increases by 1N, the frequency will increase by (24.6 ± 0.8) Hz. The calculation supports the hypothesis of a positive linear relationship between the square root of tension and the harmonics frequency. This is because the increase in mass hanging on one side of wire causes the weight on the wire to increases, so the wire becomes tighter leading to the increase in tension, resulting in a higher frequency based on Mersenne's law.

The coefficient of the square root of tension of the nichrome wire was further calculated as (9131.8 ± 0.6) kgm^{-3}

The measured coefficient of the square root of the tension of the wire nichrome has an absolute uncertainty of (±0.8) N, and this is equivalent to a percentage uncertainty of $\frac{0.8}{24.6} \times 100\% = 3\%$ and this shows that the coefficient of the square root of tension is precise and believed to be reliable. In addition, considering the spread of points around the line of the best fit, it also indicated the reliability of my results.

The line of best fit does go through the origin and this is expected. The background predicts there is no y-intercept value, and the (3±3) Hz shows the minimum y-intercept is 0 Hz, which is through 0 Hz. Therefore, there is less systematic error in the data.

The theoretical density of nichrome wire is around 8400 kgm^{-3} at the room temperature, while the experiment wire nichrome density is 9131.8 kgm^{-3}. The percentage error can be calculated by using the formula:

$$\text{percentage error} = \left|\frac{\text{theoretical value} - \text{experiment value}}{\text{experiment value}}\right| \times 100\%$$

Therefore, substituting the theoretical value and experiment value of the density, the percentage error is:

$$\text{percentage error} = \left|\frac{(8400) - (9131.8)}{9131.8}\right| \times 100\%$$

$$\text{percentage error} = \left|\frac{-731.8}{9131.8}\right| \times 100\%$$

$$\text{percentage error} = 8.0\%$$

This percentage error was calculated based on assumption that the nichrome wire is tested at room temperature. The percentage error indicates an accurate result.

Evaluation:

Although the hypothesis is corroborated by the results Mersenne's holds, which states that an increase in tension will increase the frequency of a spring, the best fit line's y-intercept is above the expected value, though with the uncertainty the experiment value can pass 0, but the systematic error still exists in the experiment. The possible reasons for this discrepancy could be the weakness throughout the experiment. At the same time, there are some strengths which led to the success of this investigation. In the following session, the strength and weakness of the investigation will be reflected and identified.

Table 7 below lists the strength of the investigation:

Strength	Significance
The entire experiment was conducted in a sealed laboratory with only myself present.	Noise interference can cause fluctuations in frequency data, leading to inconsistent measurements. By keeping the laboratory quiet, random sound interferences are minimized, ensuring more consistent and repeatable outcomes. This guarantees that the measured frequency is only from the vibrations of the nichrome wire, making the data more precise and accurate, thus reducing random error.
The smartphone used for testing the experiment was fixed in place, and the nichrome wire was plucked at the same location.	Plucking the wire in different locations can cause variations in the distance from which the app collects frequency data. Therefore, by securing the smartphone in a fixed position and plucking the wire consistently at the same spot, random errors are reduced, making the experiment more precise.
The experiment was completed within half an hour on a single day.	The formula $f^2 = \frac{1}{4L^2A\rho}F$ shows that changes in density significantly affect the results, as temperature variations cause thermal expansion and contraction. This is especially critical for materials with substantial density, where even slight temperature changes can alter density and skew results. Conducting the

	experiment within half an hour on the same day minimizes temperature fluctuations, stabilizing the density and enhancing the precision and accuracy of the data, thereby reducing random error.

Table 7 Strength of the investigation

Table 8 below list the weakness or limitations of the investigation:

Weakness or limitations	The consequences	Improvement
The experiment did not replace a new nichrome wire every time the IV was changed	Tension causes the wire to expand, reducing its cross-sectional area. According to the formula $f^2 = \frac{1}{4L^2A\rho}F$, a smaller cross-section results in a increases *f*, leading to experimental results which are higher than theoretical predictions. Using the same nichrome wire without properly controlling for these variables introduces a positive systematic error, making the frequency data inaccurate.	The best way is to replace a set of data with a new nichrome wire to reduce the impact of cross section on density and thus reduce random error. However, expansion of nichrome wire will still reduce cross section and generate random error. This cannot be perfected by means.
The experimental instrument has friction	In this experiment, friction is generated when the nichrome wire touches the pulley and the support at point A, which causes the tension to decrease. At the same time, different tension causes different friction. This results in a tension measurement which is larger than the theory, so being inaccurate and imprecise produces a positive systematic error.	It is possible to apply lubricating oil to both point A and items in contact with the nichrome wire, greatly reducing the impact of friction on tension and thereby reducing systematic error.
The accuracy of the measurement by the mobile app was not tested	The frequency set in the Tunable app may not be the standard frequency, which can lead to systematic error and make the experiment inaccurate.	To test the accuracy of the Tunable app and reduce systematic error, you can first play a precise frequency.
This data is valid only when the tension is 1050N to 1850N	Since no data above or below this range is used in this experiment, random error or systematic error may not be present only within this range. The analysis leading to the conclusion evaluation will be	Conduct more sets of experiments to see if there are other trends in the data leading to random error or systematic error, and improve the experiment.

	lacking.	

Table 8 Weakness or limitations of the investigation

Reference

1: “[PDF/ePub] Ebook Hodder Physics for the IB Diploma 2nd Edition.” *interesEdu.Com*, 5 July 2023, www.interesedu.com/item/ebook-hodder-physics-for-the-ib-diploma-2nd-edition/.

2: “Alloy 650 (Nichrome 80).” *Pelican Wire*, 16 Sept. 2021, pelicanwire.com/alloy/alloy-650-2/.

3: “Overtones.” *Encyclopædia Britannica*, Encyclopædia Britannica, inc., www.britannica.com/science/sound-physics/Overtones. Accessed 12 May 2024.
\