# IBDP PHYSICS IA MAY 2025

## Difference in frequency of guitar strings with its thickness

Word Count: 2142

**INTRODUCTION**:

I started playing the guitar when I was seven years old, and till date, it has been twelve years, and I have learnt every aspect of it. I have mastered guitar at the level where if anybody gives me any random song to play, I can learn and play it in around 10-15 mins. Playing guitar is one of my main hobbies and the one which I am good at. I am also fond of physics since my ninth grade and when we were taught about waves, frequency, amplitude, etc, I could relate with it. I never thought that playing a simple song on guitar involves such complex and in-depth physics. That is the time when I really started liking physics. I started thinking that if every fret when hold, will have a different frequency, I would like to study how guitars are made and does the making of it involves any such kind of physics.

**RESEARCH QUESTION:** Does the frequency of guitar strings change with the changes in thickness of strings ( 0.5334mm, 0.7366mm, 0.9906mm and 1.1938mm) of fixed length (57.4cm) made of Bronze material ?

**BACKGROUND:**

Table 1: Variables, Units and Meanings:

| Variables | SI Unit | Meaning of the unit |
|---|---|---|
| $L$ | $m$ | Length of the string |

| | | |
|---|---|---|
| $\lambda$ | $m$ | Wavelength |
| $v$ | $m \times s$ | Wave speed |
| $T$ | $kg \times m/s^2$ | Tension |
| $f$ | $Hz$ | Frequency |
| $\mu$ | $kg/m$ | Linear mass density |

In this experiment, I will be using a semi-acoustic guitar which consists of four bronze strings, and two plain metal strings. But I must use same material and therefore, the two plain metal strings are excluded, and the experiment will be conducted on the last four strings made of bronze. Either plucking or striking can be used to produce the sound from the guitar, and this can be done using a plectrum(pick) or using your own fingers, which will cause them to vibrate. The vibrations are then transferred to the guitar's soundboard. via bridge which will cause the air inside the hollow body to vibrate. The sound is amplified by these vibrations by the hollow guitar body which is then resonated via air in the hollow body and then exits from the sound hole of the guitar.

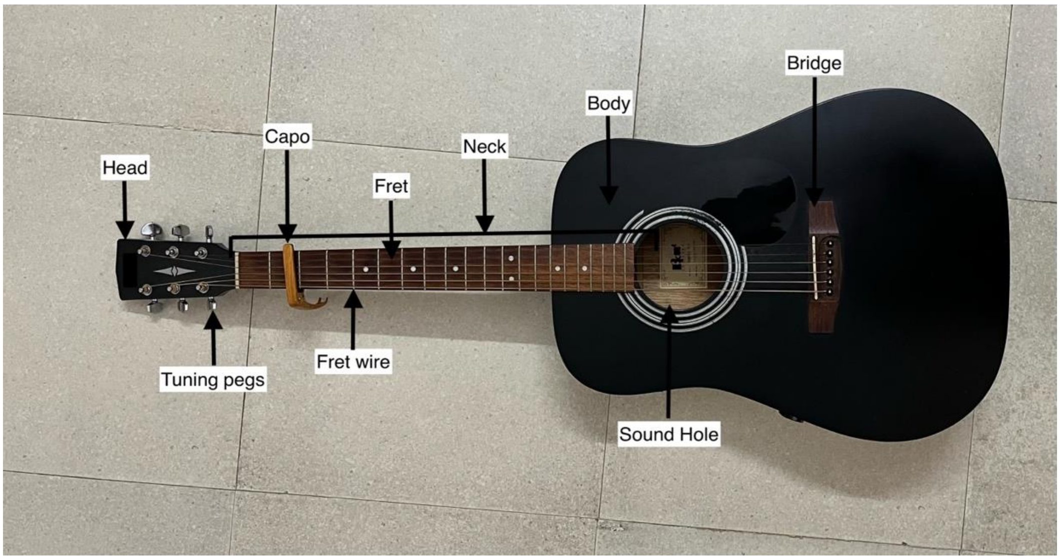


Image 1: Labelled parts of a guitar

As the string of the guitar is struck, a standing wave which are also called as stationary waves are formed between the starting of the string where capo is placed and the boundaries of guitar called the bridge. Stationary waves are wave patterns which are oscillated in time but its position is static. There is one condition for the boundary on in this case, it is that both the ends are fixed. Formation of different wave patterns is depended on the frequency of vibration. First Harmonic is one of the most basic wave pattern, which is also called as fundamental frequency. This wave pattern includes of an antinode and two nodes at both ends of the boundaries. The nodes indicate that the standing wave exhibits zero displacement. and the antinode indicate that the displacement at that point is at its maximum. The diagrams below show the wave pattern of the first harmonic:

The First Harmonic:[1]

$$\lambda = 2L$$

Wave Speed of the String:[2]

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

Relationship between Wave Speed, Frequency and the Wavelength:[3]

- For any wave, the speed $v$, frequency $f$ and wavelength $\lambda$ are related by this equation

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[1] Hamper, Chris. *Standard Level Physics*. 2014. 2nd Edition ed., Harlow, Pearson Education, 2014.

[2] Tsokos, K A. *Physics for the IB Diploma : Standard and Higher Level*. 7th ed., Cambridge ; Singapore, Cambridge University Press, 2023.

[3] Hamper, Chris. *Standard Level Physics*. 2014. 2nd Edition ed., Harlow, Pearson Education, 2014.

$$v = f\lambda$$

Substitute $v$ and $\lambda$ into the equation and rearranged to solve for $f$:

$$\sqrt{\frac{T}{\mu}} = f \cdot (2L) \text{ or } f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$$

## HYPOTHESIS:

The fundamental frequency of the strings will be affected by the diameter of the string because as the string gets thicker it gains more mass which will result in slow vibration of that string. When the diameter of the string's variation is increased at constant tension, it will be witnessed that the fundamental frequency of the string is lower as the speed of the vibration will decrease gradually.

## VARIABLES:

1) **INDEPENDENT VARIABLE:** Thickness of guitar strings, 0.533mm, 0.734mm, 0.991mm and 1.19mm (all the values are written in three significant figures).
2) **DEPENDENT VARIABLE:** Frequency of the sound when the string is plucked. As each string when plucked has its own frequency, I have used it as my dependent variable.
3) **CONTROL VARIABLES:**

- **Material of the strings:** The last four strings of the guitar I chose are made of bronze which does not change.

- **Length of the strings:** The length of every string is equal as I have placed a capo on the second fret of the guitar. A capo placed on whichever fret, the frets below the capo are null, or simply do not work/unable to play.

- **Tension(force) on the guitar strings when plucked:** When the guitar strings are plucked, the force acting on it should also be constant to get accurate frequency, hence the tension will not change.

# METHODOLOGY:

## MATERIALS:

1) Last four strings of the guitar
2) Acoustic Guitar
3) A guitar capo
4) One rubber band
5) One guitar tuner
6) Two stands
7) Marker
8) One laptop

## APPARATUS:

1) Mobile phone with frequency measuring application
2) One measuring scale (0.1cm least count and 30cm range)
3) A Vernier force sensor (0.01N least count and $\pm 10N$ range)
4) One spring balance (0.1N least count and 5N range)
5) One digital calliper (0.0001mm least count and 1000mm range)

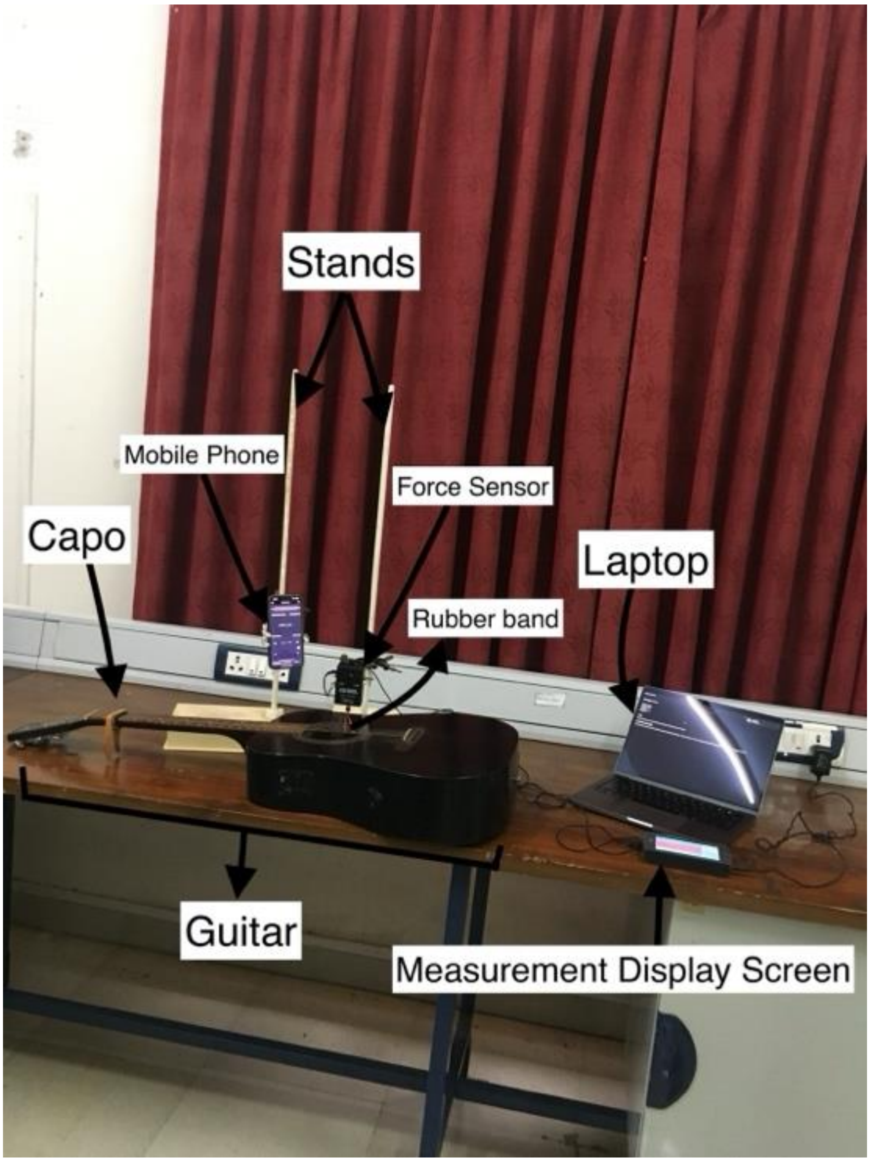



Figure 3: Labelled Setup

## METHOD:

In this experiment, I will be studying the frequency of guitar strings which are made of same bronze material and, because I had to choose the same material, I included only last four strings of the guitar called, ‘G, D, A, $E_{low}$’ and excluded the first two strings called '$E_{high}$, B', because there are six strings in total and the first two strings are made of plain steel. Additionally, to keep the length of the strings equal, I used a capo which when put to any fret, the frets below it are not functional or simply null and I put the capo on the second fret precisely above the first fret wire to keep the lengths for all four strings equal. A capo is a tool that is used to clamp on the guitar neck so that the musicians can play with a different pitch in ease and without changing the shape of the chords. I have used the standard tuning of guitar before clamping the capo on the guitar neck, so it can be said that it is relative to standard tuning. And the most challenging part was to keep the force constant while plucking each string, and to keep the force constant, I had used a rubber band which I put below each string I want to pluck and then I pull both ends of the rubber band from up to 3cm and then I leave one end of the rubber band so that it acts like a slingshot and will play the string with same force, and I have used the same rubber band for all four strings to get accurate readings, and I also marked one spot from which the guitar strings were plucked. After this, I measured the frequency through a mobile app called 'Detect Pitch', when I pluck the strings with the rubber band and when the sound is caught by the app, it shows the frequency of the string plucked. Also to get more accurate readings of the frequency, I performed this experiment in a silent place at 2am in the morning so that there is less background noise and to avoid air resistance, I ensured that before performing the experiment, all the windows and doors are closed.

## DATA COLLECTION AND PROCESSING:

- Raw data collection

Table 2: Five trials for frequency measurement for 4 different thickness of the guitar strings with capo on second fret.

| | **Frequency Trials $\pm 0.05Hz$** | | | | |
|---|---|---|---|---|---|
| **Diameter of Strings: $\pm 0.1cm$** | $f_1$ | $f_2$ | $f_3$ | $f_4$ | $f_5$ |
| G: 0.5334mm | 220Hz | 223Hz | 224Hz | 221Hz | 219Hz |
| D: 0.7366mm | 165Hz | 163Hz | 166Hz | 162Hz | 167Hz |
| A: 0.9906mm | 123Hz | 123Hz | 121Hz | 125Hz | 126Hz |
| $E_{low}$: 1.1938mm | 92.5Hz | 92.2Hz | 92.4Hz | 92.5Hz | 92.7Hz |

- **Note:** All the values in the table are rounded off to three significant figures.

- Sample calculation for average of the frequency trials for G string:

$$f_{avg} = \frac{f_1+f_2+f_3+f_4+f_5}{5}$$

$$f_{avg} = \frac{221+223+224+221+219}{5}$$

$$f_{avg} = \frac{1108}{5} = 221.6Hz = 222Hz$$

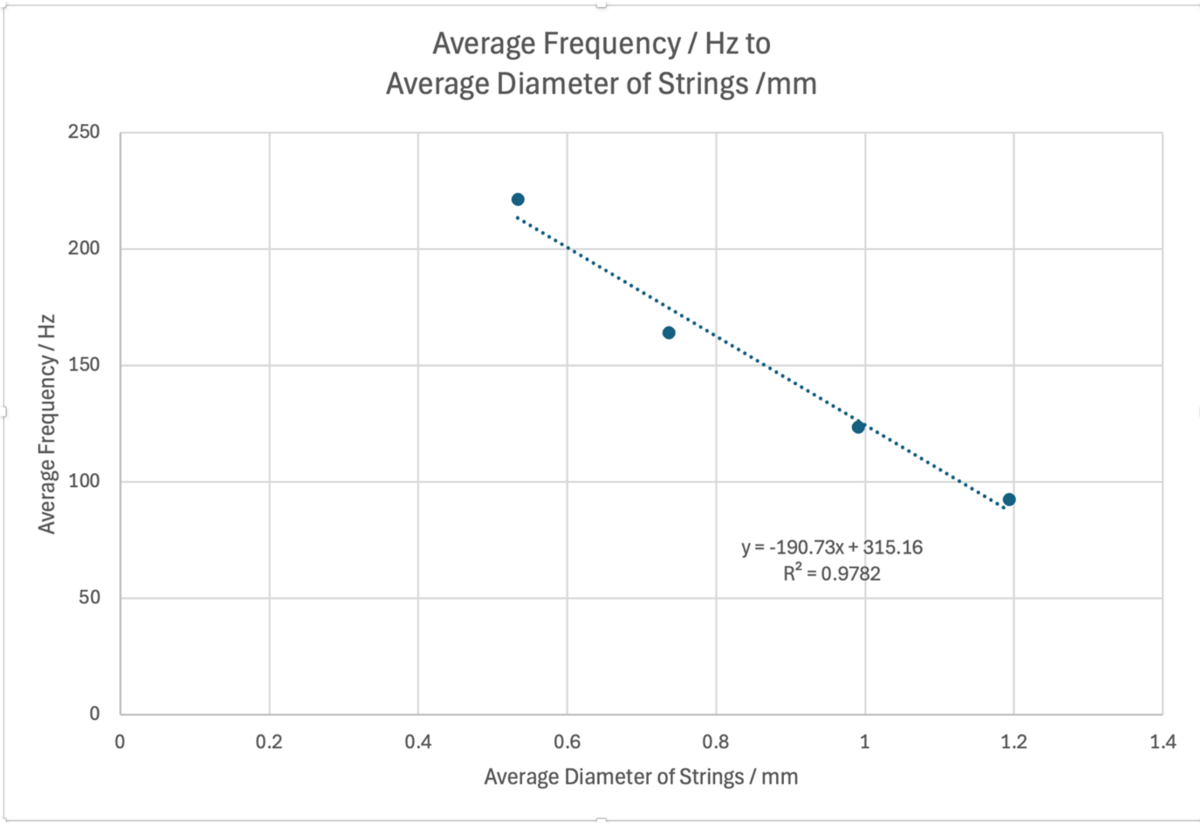
Table 3: Processed and error data table for frequency measured for five different guitar strings.

| Diameter of Strings: 0.1mm | **Average Frequency** $\pm 0.05Hz$ | **Error in Frequency** $\Delta f$ |
|---|---|---|
| G: 0.5334mm | 222 | 2.5 |
| D: 0.7366mm | 165 | 2.5 |
| A: 0.9906mm | 124 | 2.5 |
| $E_{low}$: 1.1938mm | 92 | 0.25 |

- Absolute Uncertainty Calculation:

Sample calculation for Frequency for G string:

$\Delta f = (f_{max} - f_{min}) / 2. = (224 - 219) / 2. = 2.5$ Hz




## Graphical analysis:

The graph witnessed above represents the relationship between the diameter of guitar strings and their produced average frequency. The error bars are not visible in the graph because they are too small to be seen by the naked eye. The graph discloses a crystal-clear negative correlation, and it elucidates that as the frequency decreases, the string diameter increases. The equation of line, $y = -190.73x + 315.16$, states that the frequency will drop down by 192Hz with every mm growth in diameter, which begins from 315.16Hz when the diameter is near zero, and the approximate $R^2$ value of 0.98 is a very strong indication of linear relationship. The data collected is in order according to the physics used in string vibration, where thicker strings will have more mass, which leads to production of lower frequencies. It is confirmed that the graph can validate this effectively, it uses only four data points, therefore addition of more mensuration's could improve precision.

## CONCLUSION:

In my physics IA, I have explored that how the frequency gets affected by the thickness of guitar strings while keeping the tension(force), length, material constant. In my IA, I have used a semi-acoustic guitar, and I have experimented strings of disparate diameters and noticed consistent drop down in frequency. This is all the same with the physics used in string vibration, where thicker strings which have a higher mass per unit length vibrates more slowly and generates lower frequencies.

Visual representation of the outcome can be seen in the graph, where a strong negative linear correlation between thickness of the string and frequency is witnessed. The equation $y = -190.73x + 315.16$ with an approximate $R^2$ value of 0.98 demonstrate a highly precise linear relationship. The slope of line noticeable in the graph indicates that for every 0.0001mm increase in the diameter of string, frequency drops down by 192Hz approximately. It can be said that such strong correlation justifies the reliability of the data and is in order with the theoretical explanations.

## EVALUATION:

In my IA, I have demonstrated a strong practical design with clearly focusing on the relationship between the gauge of the string and frequency. There has been use of static controls, such as maintaining the tension applied on the string, length of the string, and the material of the string constant, ensuring the accuracy of the outcomes. The collected data is close to pinpoint accurate, and there is strong linear correlation witnessed ($R^2 \approx 0.98$) exhibits the dependability of the measurements. The graph delivers a transparent visual representation, effectively assisting the study.

However, the experiment has some constraints. The small figures of data points limit the spectrum of conclusion that can be drawn. A broader dataset would not only enhance the preciseness of the trend line, but it also could've tested the consistency of the observed relationship. Furthermore, the IA focuses exclusively on one variable without discovering other fundamental factors like the impact of tension or material characteristics. Incorporating these variables could serve a more detailed picture of the physics used behind the guitar strings.

## <u>FURTHER INVESTGATION:</u>

To further investigate the topic, I could've extended the experiment to incorporate additional variables and delve into their merged effect on frequency. For example, testing different materials of strings such as nylon and steel, would've been supportive to comprehend how material characteristics like density (mass per unit volume) and elasticity impact the pitch (sound). Likewise, fluctuating the tension applied to the strings could provide knowledge within the relationship between tension, thickness and frequency. Examining harmonic frequencies beyond the essential tone could reveal how gauge of the string alters the entire scope of sound generated.

# BIBLIOGRAPHY:


Hamper, Chris. *Standard Level Physics*. 2014. 2nd Edition ed., Harlow, Pearson Education, 2014.

Tsokos, K A. *Physics for the IB Diploma : Standard and Higher Level*. 7th ed., Cambridge ; Singapore, Cambridge University Press, 2023.



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