PHYSICS 121 Experiment 8

Standing Waves

The purpose of this lab is to study standing waves on a vibrating string.

Equipment

1 electro motor with flag blocking the photo gate beam once per turn
1 photo gate connected to the interface box
1 variable power supply controls motor speed
1 rubber band, thin gold (your vibrating "string")
1 pulley
1 ruler
1 box with weights
2 a roll of thick white non-stretching string (not shown in Fig. 1.)
1 scale to weigh the string

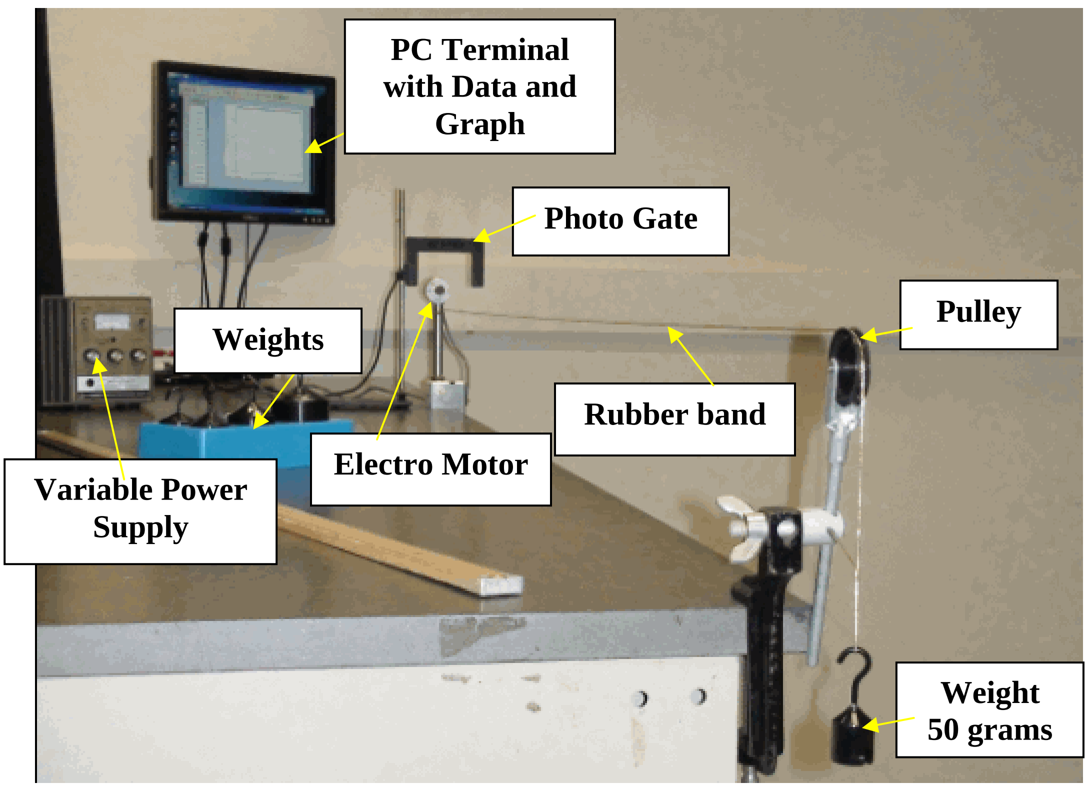

Fig. 1 a

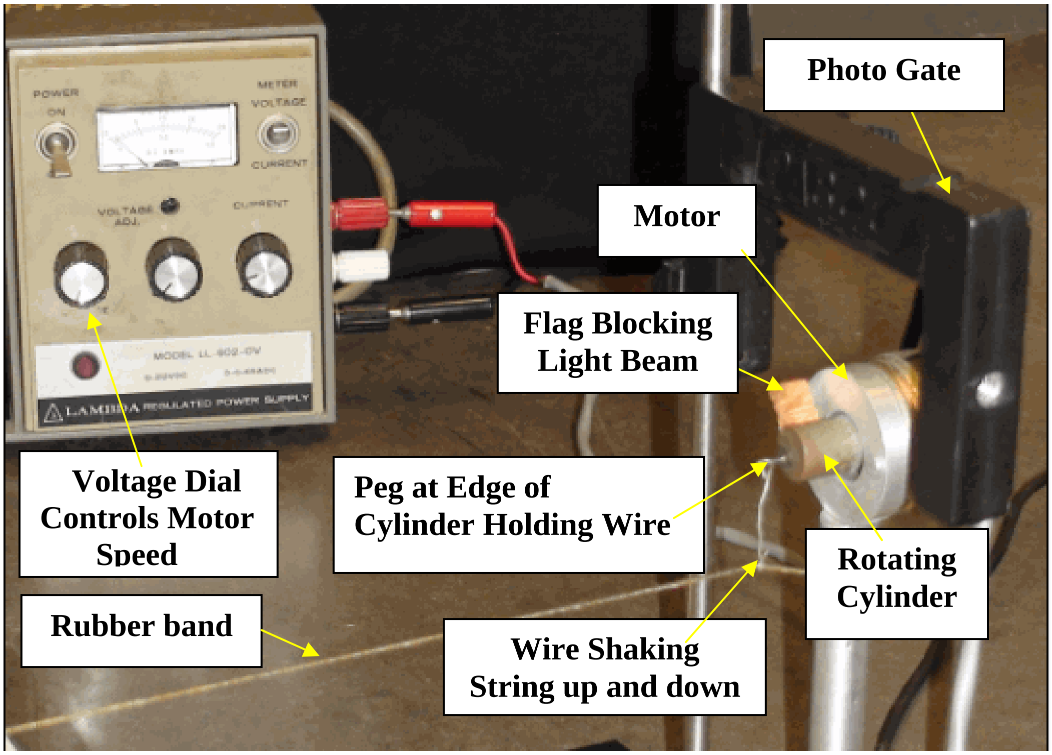

Fig. 1 b

About this Manual:

This manual has two sets of **work sheets** attached for later **online submission**:

Preparation Sheets which cover the preparatory work:
PQ1 stands for "**Preparation** Sheet **Question 1**".

Execution Sheets which cover experimental procedure, data taking and data analysis:
EQ1 stands for **"Execution** Sheet **Questions 1"**

You submit both Lab "Report #* Preparation and Execution" on MapleTA and submit your **original data tables** **initialed** by your TA and your **graphs** to your TA for a **grade**.

A) PREPARATION:

Introduction

In this lab you study **Standing Waves** on a string. You determine the **Travelling Wave Velocity** from the properties of a rubber band, then excite standing waves on this band, deduce the travelling wave velocity from them and compare. You replace the rubber band by a non-stretching string and investigate the **dependence** of the **wave velocity** on the **tension** in the string and measure the **gravitational acceleration g**.

Part I Determination of the Traveling Wave Velocity from the Tension *T* and Linear Mass Density μ;

In this part you calculate the **travelling wave velocity** ***v*** from the **tension** ***T*** in a rubber band and its **linear mass density** μ..

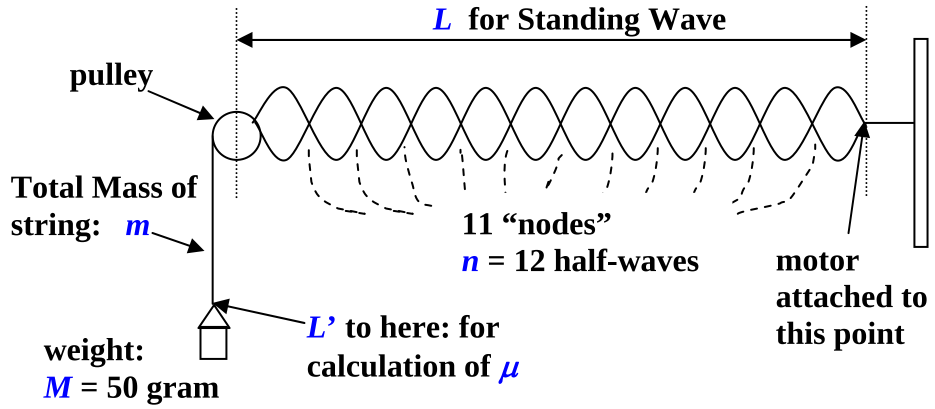

Fig. 2

In **Ch 10, sheet 20** the equation for the velocity *v* of a transverse traveling wave on a stretched string is given. Enter it as equation **(1)** on **PQ3**. The expression for the linear mass density μ of a string is given in **Ch 10, sheet 22.** Enter it as equation **(2)** on **PQ3**. Enter the expression for the tension *T* in the string, which is the suspended weight $M\,g$, as equation **(3)** on **PQ3.**

Part II Measurement of the Traveling Wave Velocity Using the Frequencies of the Observed Standing Waves on the Rubber Band:

In this part you excite **standing waves** on the rubber band at resonance frequencies f_n (***n*** is the **number of half waves** fitting into the string – see Fig. 2 above) and deduce from a graph of f_n vs n the travelling wave velocity, comparing it to Part I.

The equation for the frequencies f_n of the standing waves on a string are given in **Ch 10, sheet 19**. Enter the expression as equation **(4)** on **PQ6**. Write this equatin in the form f_n = […] *n*. The term […] is the **slope** ***k*** of the corresponding linear graph when plotting f_n vs n. Relate the travelling wave velocity v to *k* and enter the relation as equation **(5)** on **PQ6**.

Part III Verification of the Dependence of the Traveling Wave Velocity on the String Tension *T* and a Measurement of the Acceleration of Gravity *g*:

In this part you measure the **dependence** of the **frequencies** f_n on the **tension** T in a non-stretching string. You vary the tension by suspending various weights of mass ***M*** from the string. You keep the number of half waves **fixed** at ***n* = 3**.

Combining equations **(1)** and **(3)** on **PQ3** and equation **(4)** on **PQ6**, write the square of f_3

in the form $f_3^2 = [\ldots]\, M$ and enter it as equation **(6)** on **PQ8**. The term [...] is the **slope** k of the linear f_3^2 vs M graph and contains the **acceleration of gravity** *g*. Equate k to this term and give *g* in terms of the *k*. Enter this as equation **(7)** on **PQ9**.

B) EXECUTION:

Part I Determination of the Traveling Wave Velocity from the Tension *T* and Linear Mass Density μ;

Determine the mass *m* and the length *L'* (see Fig. 2) of the rubber band while it is **under tension** with a suspended weight of *M* = 50 grams. Assign an absolute error of 0.1 gram to *m* and an absolute error of 1 *cm* to *L'* if you have to estimate the amount of loops and knots in the band, otherwise smaller. Enter your values into the table on **EQ1**.

Give the equation for the **absolute error** $\Delta\mu$ of the linear mass density, using equations **(7)** and **(4)** in **"Error and Uncertainty"** and equation **(2)** in **Preparation.**

Give the equation for the absolute error of the travelling wave velocity *v* treating the tension *T* as error free. Use equations **(3), (8)** and **(4)** in **"Error and Uncertainty".**

Enter both relations as equations **(8)** and **(9)** on **EQ2.**

Calculate the values of T, μ and $\Delta\mu$ and enter them on **EQ3**.

Calculate the values of the travelling wave velocity v on the rubber band and its absolute error Δv and enter them on **EQ4**.

You compare this value to the one measured in Part II below.

Part II Measurement of the Traveling Wave Velocity Using the Frequencies of the Observed Standing Waves on the Rubber Band:

The rubber band is strung over a pulley from which the weight is suspended. A small electro motor on the other end of the band is driven by a variable power supply and provides the oscillatory driving force, which generates a traveling wave on the band. The wave is reflected back along the string at the pulley, and is reflected again at the vibrator. When the second reflected wave is in phase with the original wave, a standing wave pattern will be observed on the string as sketched in Fig. 2 above. **The distance between the nodes of the standing wave is one-half of the wavelength of the wave**. "Nodes" are points of destructive interference where the rubber band remains still and anti-nodes are points of constructive interference where the band oscillates with maximum amplitude.

Sketch on the grid in **EQ5** a standing wave pattern for a wave with **several half-waves** fitting into the length *L* on Fig. 2. Label it with the number of half-waves, nodes and the length of the rubber band, using the correct symbol from Fig. 2. **Submit** the sketch to your **TA** for a **grade.**

Get your computer and photo gate ready for data taking:

Place the motor in the photo gate such that the **flag** attached to the cylinder in the center of the motor blocks the light beam of the photo gate, when the flag is raised.

Connect the photo gate output to the interface box by plugging its cable into the **top** socket (labeled "DIG/SONIC 1") of the black interface box ("LabPro").

Turn on the computer and check the system by following these instructions: Double click the icon "**Exp8_Period**". A window with a spreadsheet on the left (having "State, Pulse Time" columns and a graph labelled "Pulse Time") comes up. On top is a window "**Sensor Confirmation**".

Click "Connect", again "Connect".

Test the photo gate: block the photogate beam with your finger and see the red light on the cross bar of the photogate turn on.

Click OK.

You are ready for data taking now.

Vary the frequency of the driving motor by varying the voltage from the power supply (see Fig. 1 above) and observe standing waves as sketched in Fig. 2, whenever the driving frequency is equal to a frequency, which obeys equation **(4)** on **PQ6,** the **allowed resonance frequencies** of the rubber band under tension. Once you have a stable pattern click the green icon "Collect" on the PC screen and take a few measurements.

The times you see on the PC screen on the left are measured **periods** T of a motor revolution. Thus $f = \frac{1}{T}$ is the **frequency** with which the rubber band is skaken. You see on the right a horizontal line, since all periods are equal as time goes on.

Measure the length L (see Fig 2 above) with the ruler, estimate its error and enter both on **EQ6**. Establish **at least 7 consecutive resonance frequencies** f_n and enter the values of 7 of them, together with the number of half waves n, on **EQ6**. Graph f_n vs n on the grid in **EQ7.** **Include** the point **(0,0)** as an error free point**.** Label **axes**, **scales** and horizontal and vertical **intervals** used for the measurement of the slope k and its error Δk. Enter them on **EQ7**.

Submit your graph to your **TA** for a **grade**.

Use equation **(5)** in **Preparation** to get the expression for the absolute error Δv of the travelling wave velocity v (apply equations **(7)** and **(4)** in **"Error and Uncertainty").** Enter it as equation **(10)** on **EQ8.** Calculate the values of v and Δv and enter them on **EQ9**.

Compare the values of v from Part I and Part II in **EQ10**.

Part III Verification of the Dependence of the Traveling Wave Velocity on the String Tension T and a Measurement of the Acceleration of Gravity:

Replace the "rubbery" string with the thick white string. The string does not stretch noticeably when put under tension, thus having a fixed linear mass density for various tensions. Determine its linear mass density μ as you did it for the rubber band in Part I. Use the same error estimates for *m, L, L'* as in Part I and II. Enter your measurements and your result for μ in **EQ11.**

Vary the tension T by suspending masses M = 50, 100, 150, 200 grams. Measure the frequency f_3 for the standing wave with **3 half – waves** and enter them with their squares f_3^2 in **EQ12**.

Graph f_3^2 vs M on the grid in **EQ13**. **Include** the point **(0,0)** as error free point. Label **axes, scales** and **intervals** used for the measurement of the slope k and its error Δk. Enter them on **EQ13.**

Submit your graph to your **TA** for a **grade**.

Use equation **(7)** in **Preparation** and equation **(3), (7)** and **(4)** of **"Error and Uncertainty"** to get the equation for the absolute error Δg of **the acceleration of gravity** *g*. Enter it as equation **(11)** on **EQ14**.

Calculate the values of g and Δg and enter them on **EQ15**.

Compare your result with the **accepted** value of g = 9.81 m/s^2 in **EQ16**.