MINISTRY OF EDUCATION AND TRAINING
NONG LAM UNIVERSITY

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Course:

Introductory Physics Experiments 2

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Chapter 1

ERRORS THEORY

When measuring a quantity we must use instruments and our senses. Therefore, we cannot determine the exact value of the quantity to be measured. On making different measurements of a particular quantity we often obtain different values; it means that we have errors on this quantity.
There are different types of errors and each type of error required different calculation. For example, a quantity to be measured, called **X**, after several measurements have been made and then analyzed, the results must be wriiten as follows:

$$X = \overline{X} \pm \overline{\Delta X} \tag{1.1}$$

Where X is the quantity to be measured, $\overline{X}$ is the **avarage value** of X, and $\overline{\Delta X}$ is the **average absolute error value** on measuring X.

1.1 The average value of quantity X

It is denoted by $\overline{X}$ and given by

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{1.2}$$

where n is the number of measurements made on X, and X_i is the value of X obtained in the ith measurement.

1.2 The average absolute error

It is denoted by $\overline{\Delta X}$. This quantity gives the uncertainty of the value to be obtained of X and is given by

$$\overline{\Delta X} = \overline{\Delta X}_{random} + \overline{\Delta X}_{instrument} \tag{1.3}$$

where ΔX_{random} is the **average error due to the randomness** and $\Delta X_{instrument}$ is that due to **instrumentation**. This quantity gives the uncertainty on measuring X.

1.3 The average error due to randomness

It is denoted by ΔX_{random}. This type of error is due to the inherently random nature of measuring directly a particular quantity many times. It depends on several factors: the quantity to be measured, the accuracy of the instruments, human's limited capability of reading, and external environment. As a result, each measurement of the same quantity gives a little bit different values.
ΔX_{random} is given by

$$\overline{\Delta X}_{random} = \frac{\sum_{i=1}^{n} \left| X_i - \overline{X} \right|}{n} \tag{1.4}$$

1.4 The instrumental error

It is denoted by $\Delta X_{instrument}$. This type of error is due to the lack of accuracy of the instruments.
It is calculated as follows:

- Reading the value on using the instrument. For example, on the micrometer, the lowest division is $0.01mm$, thus $\Delta X_{instrument} = 0.01mm$.
- Getting or $\frac{1}{2}$ of value of the lowest division. As a result, for example, on the micrometer, the lowest division is $0.01mm$, thus $\Delta X_{instrument} = 0.01mm/2 = 0.005mm$.
- For electrical instruments such as ammeter, voltmeter, etc., we have by convention $\overline{\Delta X}_{instrument} = 1\% X_{max}$. Where X_max is the *lowest division* of the instrument used.

Noting that, in *these experiments of this section* we only get the value of $\Delta X_{instrument}$

$$\overline{\Delta X}_{instrument} = \textbf{the lowest division} \tag{1.5}$$

Consequently, the instrument should be chosen so that the instrument's measuring scale is at the nearest to the value to be measured. The instrumental error is then small, giving the smaller value of and better accuracy of the measurement. Combining equations (1.2), (1.3), (1.4), (1.5) we obtain the final result (1.1).

1.5 The average relative error

It is denoted by $\bar{\epsilon}$ and given by

$$\overline{\varepsilon} = \frac{\overline{\Delta X}}{\overline{X}} \tag{1.6}$$

The average relative error is used to evaluate the accuracy of the measurement. Therefore, to evaluate the accuracy of the measurement we need to find both the **average relative error** and the **average absolute error**.

1.6 Formulae to find errors indirectly

This is shown on the table below

Table 1.1: The formulae to calculate errors

X(a,b,c)	$\overline{\Delta X}$	$\overline{\varepsilon} = \frac{\overline{\Delta X}}{\overline{X}}$
$a + b + c$	$\overline{\Delta a} + \overline{\Delta b} + \overline{\Delta c}$	$\frac{\overline{\Delta a}+\overline{\Delta b}+\overline{\Delta c}}{\overline{a}+\overline{b}+\overline{c}}$
$a - b$	$\overline{\Delta a} + \overline{\Delta b}$	$\frac{\overline{\Delta a}+\overline{\Delta b}}{\overline{a}-\overline{b}}$
$a \times b$	$\overline{a}.\overline{\Delta a} + \overline{b}.\overline{\Delta b}$	$\frac{\overline{\Delta a}}{\overline{a}} + \frac{\overline{\Delta b}}{\overline{b}}$
a^n	$n(\overline{a})^{n-1}\overline{\Delta a}$	$n\frac{\overline{\Delta a}}{\overline{a}}$

1.7 Writing the results and rounding the numbers

The value of the quantity to be measured is written in the form $X = \overline{X} + \overline{\Delta X}$, obeying the following rules:

1. The value of $\overline{X}$ is written in the standardized form: $\overline{X} = a \times 10^n$ with $1 < a < 10$.
2. The value of $\overline{\Delta X}$ is normally written with a non-zero digit and in accordance with the power value n of $\overline{X}$.
3. Discard the unreliable digits in $\overline{X}$ (the digit whose order is smaller than the power value n of $\overline{X}$).

Example: We have raw values: $\overline{X} = 297.159$ and $\overline{\Delta X} = 0.2765$, now follow the steps

1. Standardixing $\overline{X}$: $\overline{X} = 2.97159 \times 10^2$
2. Keeping a non-zero digit and rounding $\overline{\Delta X}$ such there is an accordance in the power between $\overline{X}$ and $\overline{\Delta X}$: $\overline{\Delta X} = 0.003 \times 10^2$
3. Discarding the unreliable digits in $\overline{X}$ and rounding the result numbers.

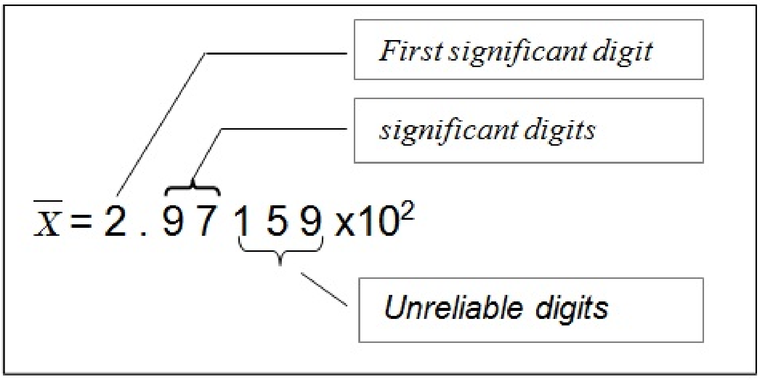

Figure 1.1: Significant and Unreliable digits.

$\overline{\Delta X} = 0.003 \times 10^2$
Thus: $\overline{X} = 2.972 \times 10^2$, Finally: $X = (2.972 \pm 0.003) \times 10^2$

Example: Determine the result of measurment of density D of the solid using the formula $D = \frac{m_1 - m_2}{m_3 - m_2} d_0$. The data are given $m_1 = (18.55 \pm 0.01)\, g$; $m_2 = (10.02 \pm 0.01)\, g$; $m_3 = (13.17 \pm 0.01)\, g$; $d_0 = (1.00 \pm 0.05)\, g/cm^3$.
Calculating D

$$D = \frac{m_1 - m_2}{m_3 - m_2} d_0 \Rightarrow \overline{D} = \frac{\overline{m_1} - \overline{m_2}}{\overline{m_3} - \overline{m_2}} \overline{d_0} = \frac{18.55 - 10.02}{13.17 - 10.02} \times 1.00 = 2.7079 g/cm^3$$

Calculation $\overline{\Delta X}$: Getting natural logarithm both sides of the equation for calculating D, we have

$$\ln D = \ln(m_1 - m_2) - \ln(m_3 - m_2) + \ln d_0$$

Differentiating this equation

$$\frac{\mathrm{dD}}{D} = \frac{d(m_1 - m_2)}{(m_1 - m_2)} - \frac{d(m_3 - m_2)}{(m_3 - m_2)} + \frac{d(d_0)}{d_0}$$

After some manipulations, it reduces to

$$\frac{\mathrm{dD}}{D} = \left[\frac{1}{m_1 - m_2}\right] dm_1 + \left[\frac{m_1 - m_3}{(m_1 - m_2)(m_3 - m_2)}\right] dm_2 - \left[\frac{1}{m_3 - m_2}\right] dm_3 + \frac{d(d_0)}{d_0}$$

Converting to $\frac{\overline{\Delta \mathrm{D}}}{\overline{D}}$

$$\frac{\overline{\Delta \mathrm{D}}}{\overline{D}} = \left|\frac{1}{m_1 - m_2}\right| \overline{\Delta m_1} + \left|\frac{m_1 - m_3}{(m_1 - m_2)(m_3 - m_2)}\right| \overline{\Delta m_2} + \left|\frac{1}{m_3 - m_2}\right| \overline{\Delta m_3} + \frac{\Delta(d_0)}{d_0}$$

Substituting the numbers, we have $\frac{\overline{\Delta \mathrm{D}}}{\overline{D}} = 0.059$
We now calculate: $\overline{\Delta \mathrm{D}} = \overline{D} \times 0.059 = 2.7079 \times 0.059 = 0.159766 g/cm^3$ The result received

$\overline{D} = 2.7079 g/cm^3$ (in standardized form)
$\overline{\Delta \text{D}} = 0.159766\, g/cm^3 \approx 0.2\, g/cm^3$: keeping one significant digit
Rewriting to make sure an accordance in power:$\overline{D} = 2.7\, g/cm^3$
Final result: $D = (2.7 \pm 0.2)\ g/cm^3$

1.8 Drawing a diagram

In many experiments, we often need to represent the results by drawing a diagram based on the collected data, depicting the relationship between two quantities of interest.
How to draw a diagram:

1. Make a data table.
2. Setting up the coordinates (an ordinate and an abscissa).
3. Putting units on the two axes
4. Choose proper scales
5. Drawing error rectangles whose centers are coincident with the measured values ($\overline{X}$ and $\overline{Y}$) and sides are $2\overline{\Delta x}$ and $2\overline{\Delta y}$, respectively.
6. Drawing a smooth curve connecting those rectangles.

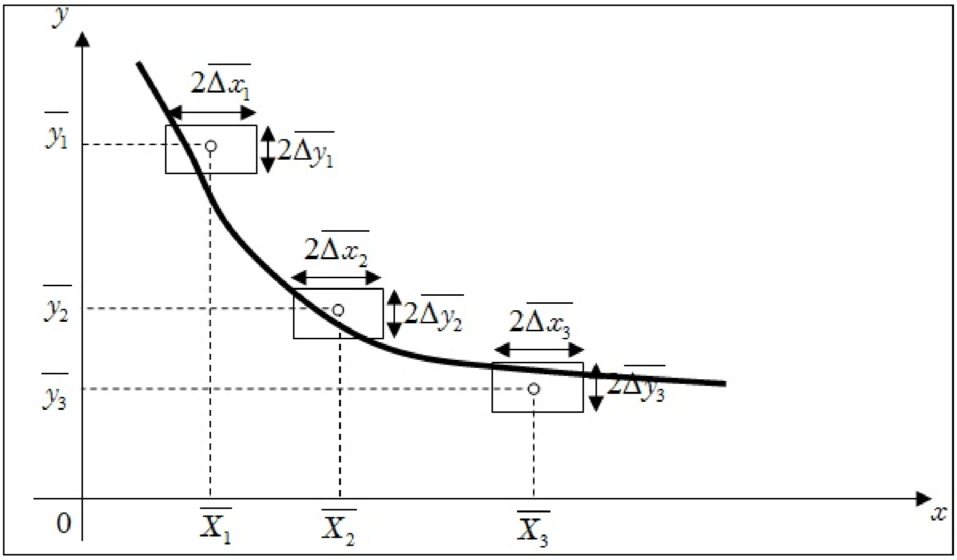

Figure 1.2: Drawing a experimental diagram.

Chapter 2

EXPERIMENTS PHYSICS 2

2.1 Determining The Viscosity Of A Liquid

2.1.1 The purposes of the experiment

- Examine the real motion of an object in a liquid under the earth's gravity.
- Applying the dynamic method to determine the viscosity of a liquid.

2.1.2 Theoretical backgrounds

The internal friction phenomenon and the Newton's law of viscosity.
Consider a liquid streaming along the Ox axis with the resistance in a cylinder, as shown in Figure 2.1. Experimental results show that velocity of liquid's molecules varies in the z direction, and the speed of the liquid's molecules reduces gradually from the middle (the symmetrical axis of the cylinder) to the sides of the cylinder. We now examine two adjacent

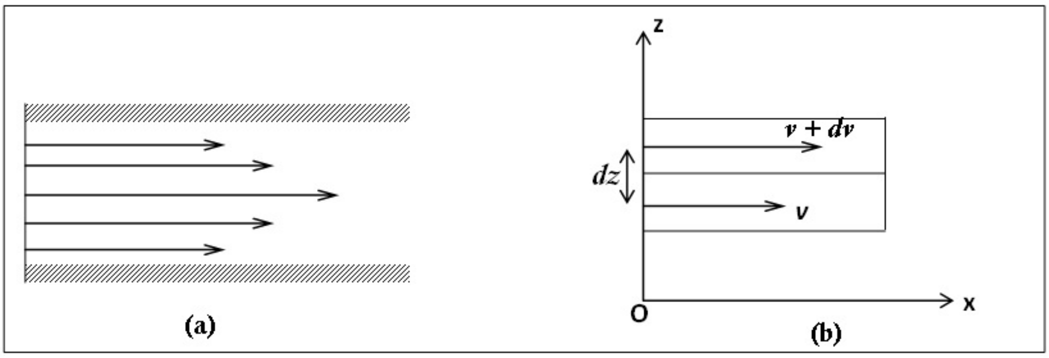

Figure 2.1: Velocity of liquid's molecules varies in the z direction, and the speed of the liquid's molecules reduces gradually from the middle to the sides of the cylinder.

layers, separated by dz, as shown in Figure 2.1(a). There is a difference in flowing speed between the two layers. Experiments show that there is a mutual interaction between this two layers: the faster layer drags the slower one as if there exists a frictional force between them. This force is termed **the internal friction** or **the viscous force**, which is tangent to the contacting surface of the two layers.

Experimental observations show that the viscous force between two fluid layers moving in the direction perpendicular to the Oz axis has its magnitude proportional to the velocity gradient in the z direction (dv/dz) and the contacting area of the two layers (ΔA):

$$f = \eta \frac{dv}{dz} \Delta A \tag{2.1}$$

Where η is the proportional coefficient, called **viscous coefficient** of the fluid. Equation (2.1) is the mathematical form of the Newton's law of viscosity. The SI unit of η is $N \times s/m^2 = kg/m \times s$.

To determine the viscous coefficient of a liquid we can use Stoke's method

Stoke's method

Consider a small sphere of radius R, that undergoes a translational motion with velocity v in a liquid. Due to the internal friction, the sphere drags a layer of liquid near its surface and sets this layer in motion. Experiments show that the width of this layer is about $2R/3$;

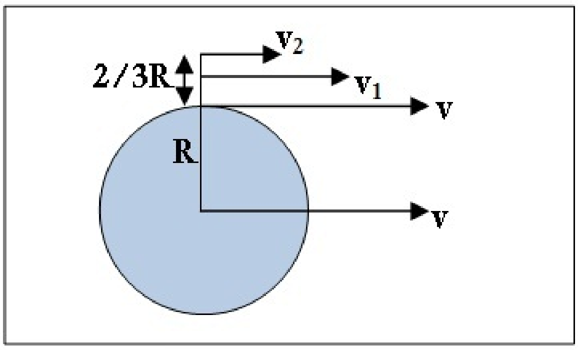

Figure 2.2: There is zero speed at a distance of $2R/3$ from the sphere's surface.

those molecules in contact with the sphere's surface have speed of v; those further away have smaller speed and those at a distance of 2R/3 from the sphere's surface have zero speed (2.2). Consequently, we can find the velocity gradient in the z direction as follows:

$$\frac{dv}{dz} = \frac{v - 0}{\frac{2}{3}R} = \frac{3}{2}\frac{v}{R} \tag{2.2}$$

According to the Newton's law of viscosity, in this case the internal friction is given as follows:

$$f = \eta \frac{dv}{dz} \Delta S = \eta \frac{3}{2}\frac{v}{R} 4\pi R^2 \Rightarrow f = 6\pi\eta R v \tag{2.3}$$

Equation 2.3 is the **mathematical form of the Newton's law**. It is valid for the fluid speed values which are not so high.

We now consider a sphere which is moving freely in a fluid. It is simultaneously acted on by three forces: the gravity force $\vec{P} = m\vec{v}$, the Archimedes force (bouyant force) $\vec{A}$, and the internal friction force $\vec{f}$, as shown in Figure 2.3. When the sphere's motion is lenearly uniform, the three forces are in balance and in magnitude. We have

$$P = A + f \tag{2.4}$$

where $P = mg = \rho_{ball} V g$; V is the sphere's volume and ρ_{ball} the sphere's density and g the gravity acceleration; ρ_{liquid} is the liquid's density. Putting all in equation 2.4, we obtain

$$\eta = \frac{\rho_{ball} - \rho_{luiquid}}{6\pi R v} \tag{2.5}$$

The sphere's volume is $V = \frac{4}{3}\pi R^3$.The sphere's speed v can be calculated if we know the

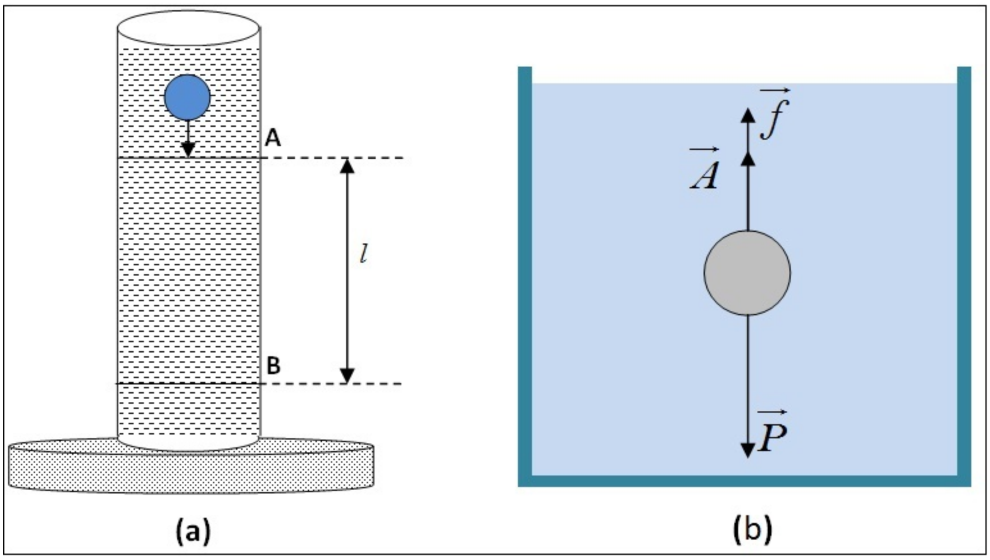

Figure 2.3: The motion of the ball under actting of three force: The gravitational force , the viscous force and the Archimedes force

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distance l between to markers A and B (Figure 2.3a) on the side of the tube which contains the liquid and the time interval t it takes the sphere to move from A to B.

$$v = \frac{l}{t} \tag{2.6}$$

Combining (2.5) and (2.6) we have

$$\eta = \frac{2}{9}\frac{(\rho_{ball} - \rho_{liquid})R^2 g t}{l} \tag{2.7}$$

2.1.3 Instruments

(1) A tube containing a liquid
(2) Some metallic balls
(3) A vernier caliper
(4) A stopwatch
(5) A ruler

2.1.4 Procedure

Step 1: Calculating the radius R of the metallic sphere (using vernier caliper)
Step 2: Calculating the distance between A and B
Step 3: Measuring the time interval t for the sphere moves from A to B. Carry five times step 1 to step 3. Each time calculate the value of η using equation 2.7 and the coresponding error.

2.1.5 Reporting

(see the reporting of unit 1)

THE REPORTING FORM OF UNIT 1

(1) Question: What is the viscous force?

(2) Experiment's result: Finish the below data sheet and calculate the average values and corresponding error. **Given**

Measurement	R	ΔR	t	Δt	η
1					
2					
3					
4					
5					
The average value					

Figure 2.4: The radius R of the ball and the time interval t for falling from A to B

.

The path of the falling: $l = AB = 0.300 \pm 0.001m$

The mass density of the ball: $\rho_{ball} = (7.880 \pm 0.005) \times 10^3 kg/m^3$

The mass density of the fluid: $\rho_{fluid} = (1.260 \pm 0.001) \times 10^3 kg/m^3$

The gravtitational acceleration: $g = (9.86 \pm 0.02)m/s^2$.

Calculating

a. The average value of the viscosity coefficient of the liquid

b. And the errors $\overline{\Delta R}$, $\overline{\Delta t}$, $\overline{\varepsilon_\eta}$, $\overline{\Delta \eta}$

Writing the final results: $\eta = \bar{\eta} \pm \overline{\Delta \eta}$

2.2 Measuring the speed of wave by observation of standing wave on a straight string fixed at both ends

2.2.1 The purpose of the experiment

This experiment is aimed at helping students to know how to measure the speed of wave in a straight string.

2.2.2 Theoretical backgrounds

Consider a straight string of length L fixed at both ends, as shown in Figure 2.5. Standing waves are set up in the string by the superposition of waves incident on and reflected from the string's ends (wave interference). Note that the ends of the string, because they are fixed and must necessarily have zero displacement, are nodes by definition. We consider

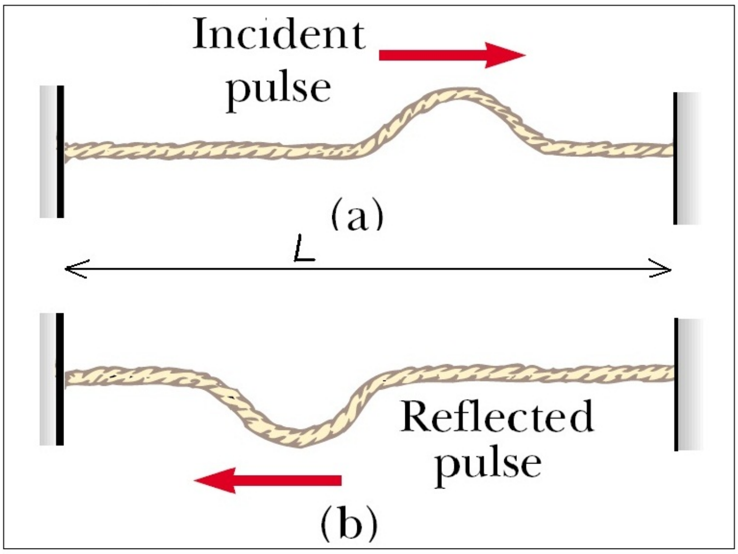

Figure 2.5: A straight string of length L fixed at both ends

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wave functions of two transverse sinusoidal waves having the same amplitude, frequency, and wavelength but traveling in opposite directions in the same medium:

$$y_1 = A\sin(kx + \omega t) \qquad y_2 = A\sin(kx - \omega t) \tag{2.8}$$

where y_1 represents a wave traveling to the right and y_2 represents one traveling to the left. According to the principle of superposition, adding these two functions gives the function of the resultant wave y:

$$y = y_1 + y_2 = (2A \sin kx) \cos \omega t \tag{2.9}$$

Where x is the particle's position on the string, measured from either end of the string, and k is the wave number. Equation (2.9) is the wave function of a standing wave. A standing wave, such as the one shown in Figure 2.6, is an oscillation pattern with a stationary outline that results from the superposition of two identical waves traveling in opposite directions. We see that Equation 2.9 describes a special kind of simple harmonic motion.

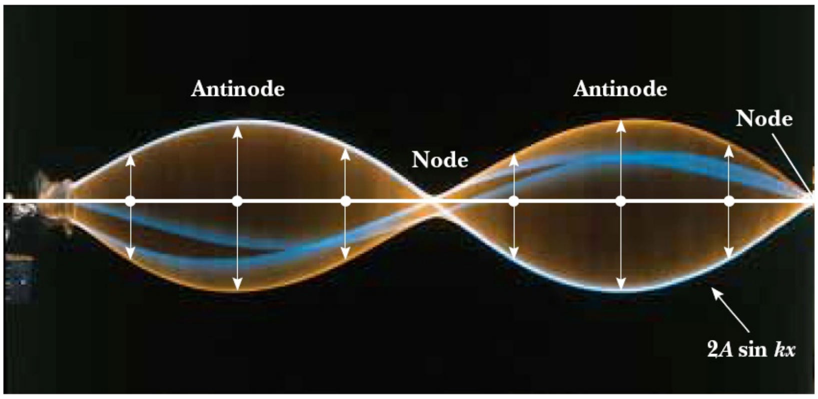

Figure 2.6: Multiflash photograph of a standing wave on a string. The time behavior of the vertical displacement from equilibrium of an individual particle of the string is given by $cos(\omega t)$. That is, each particle vibrates at an angular frequency ω. The amplitude of the vertical oscillation of any particle on the string depends on the horizontal position of the particle. Each particle vibrates within the confines of the envelope function $2Asinkx$

Every particle of the string undergoes a simple harmonic motion with the same frequency ω (according to the $cos(\omega t)$ factor in the equation). However, the amplitude of the simple harmonic motion of a given particle (given by the factor $2Asin(kx)$, the coefficient of the cosine function) depends on the location x of the particle on the string. We need to distinguish carefully between the amplitude **A** of the individual waves and the amplitude $2Asin(kx)$ of the resultant simple harmonic motion of the particles of the string. When a standing wave exists, any given particle on the string vibrates within the constraints of the envelope function $2Asin(kx)$. This is in contrast to the situation of a traveling sinusoidal wave, in which all particles oscillate with the same amplitude and frequency.

The displacement of a particle of the string has a minimum value of zero when x satisfies the condition $sin(kx) = 0$ that is, when Because $kx = \pi; 2\pi; 3\pi;...$, $k = \frac{2\pi}{\lambda}$, these values kx give

$$x = \frac{\lambda}{2}; \lambda; \frac{3\lambda}{2}; ....; \frac{n\lambda}{2} \qquad \text{n} = 0, 1, 2, 3,... \tag{2.10}$$

where λ is the wavelength. These points of zero displacement are called **nodes**.
The particles with the greatest possible displacement from equilibrium have an amplitude of $2A$, and we define this value as the amplitude of the standing wave. The positions on the string at which this maximum displacement occurs are called *antinodes*. The antinodes are located at positions for which the coordinate x satisfies the condition $\sin kx = \pm 1$ that is, when $kx = \frac{\pi}{2}; \frac{3\pi}{2}; \frac{5\pi}{2};...$ Thus, the positions of the antinodes are given by

$$x = \frac{\lambda}{4}; \frac{3\lambda}{4}; \frac{5\lambda}{4}; ....; \frac{m\lambda}{4} \qquad \text{m} = 1, 3, 5, 7,... \tag{2.11}$$

In examining Equations (2.10) and (2.11), we note the following important features of the locations of nodes and antinodes:
The distance between two adjacent antinodes is equal to $\frac{\lambda}{2}$.
The distance between two adjacent nodes is also equal to $\frac{\lambda}{2}$.
The distance between a node and an adjacent antinode is $\frac{\lambda}{4}$.
If both ends of the string are nodes, the length of the string will be

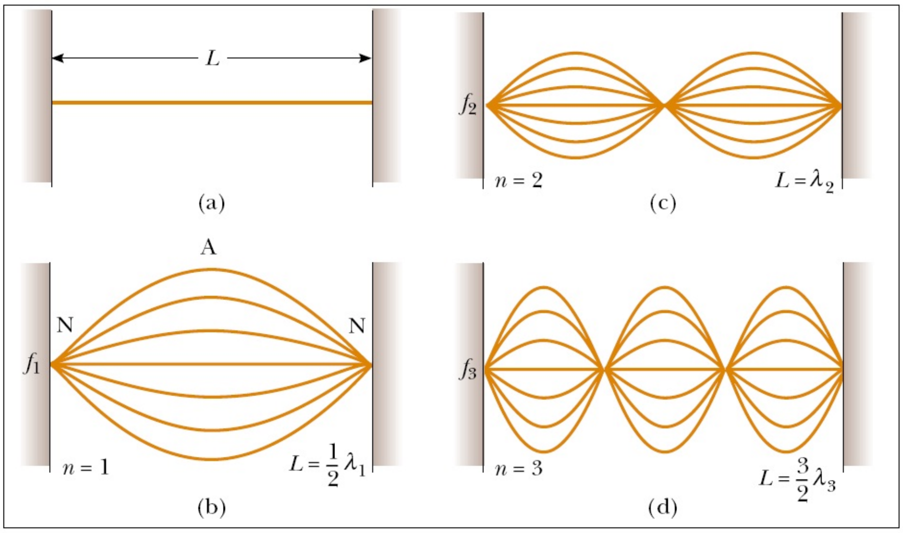

Figure 2.7: (a) A string of length L, fixed at both ends. The normal modes of vibration form a harmonic series; (b) the fundamental, or first harmonic; (c) the second harmonic; (d) the third harmonic

$$L = n\frac{\lambda}{2} \tag{2.12}$$

n is the number of antinodes. Because $\lambda = \frac{v}{f}$, combining equation (2.11) with equation (2.12), we have

$$v = \frac{2Lf}{n} \tag{2.13}$$

With this experiment, frequency f is decided by a signal generator and the length L is decided by the ruler on a testing stand. Therefore, using equation (2.13), we can find the value of the speed of wave v.

2.2.3 Instruments

(1) An elastic string
(2) A spring
(3) A dynamometer
(4) A vibrator
(5) A testing stand
(6) A signal generator
(7) A tripod
(8) Connecting wires

2.2.4 Procedure

Step 1: Arrange this experiment, as shown in Figure 2.8
Step 2: Adjust the frequency of the vibrator to set up a stable standing wave on the string. Read this value of the frequency on the signal generator and count the number of antinodes on the string.
Step 3: Continue to adjust frequency to other values for other stable standing waves on the string and count the number of antinodes for each value of frequency.

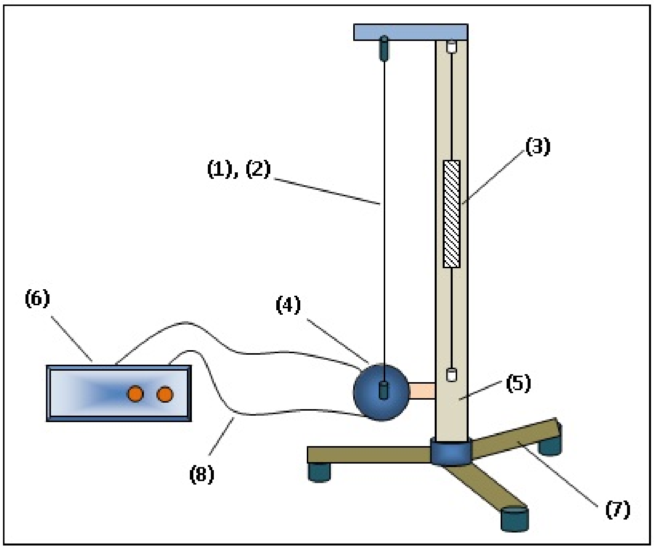

Figure 2.8: (a) A string of length L, fixed at both ends. The normal modes of vibration form a harmonic series; (b) the fundamental, or first harmonic; (c) the second harmonic; (d) the third harmonic

Note: get 4 values of frequency and 4 corresponging values of number of antinodes.

2.2.5 Reporting

(see the reporting form of unit 2)

THE REPORTING FORM OF UNIT 2

1. Give brief definitions of standing wave, node and antinode.

2. Give conditions to set up a standing wave on a string fixed at both ends.

3. Does the speed of wave on the string depend on the frequency of the vibrator? If increasing the tension of the string, how is the speed of wave change? How do you do to verify it by this experiment?

4. Are the vibrating amplitudes of particles on the string the same? If not, how do these amplitudes vary?

5. Calculate the speed of wave v_1, v_2, v_3, v_4 then find the average value $\overline{\Delta v_1}$, $\overline{\Delta v_2}$, $\overline{\Delta v_3}$, $\overline{\Delta v_4}$ and $\overline{\Delta v}$. Put these values on the below table.

6. The speed of wave on the string: $\overline{v} = \overline{v} \pm \overline{\Delta v}$

<table>
<tr><td>Frequency</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Number of corresponding antinodes</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Speed of wave</td><td></td><td></td><td></td><td></td></tr>
<tr><td>The average value of speed</td><td colspan="4"></td></tr>
<tr><td>Δv</td><td></td><td></td><td></td><td></td></tr>
<tr><td>$\overline{\Delta v}$</td><td colspan="4"></td></tr>
</table>

Figure 2.9: List of these values

2.3 Determining the moment of inertia

2.3.1 The purposes of the experiment

Determine the moment of inertia of the solid.

2.3.2 Theoretical backgrounds

Moment of inertia **I** of an object about an axis is defined as

$$I = \Sigma_{i=1}^{n} m_i r_i^2 \tag{2.14}$$

where m_i is the mass of the i-th particle and r_i the distance from it to the axis. The moment of inertia is defined with respect to an axis of rotation. For example, the moment of inertia of a circular disk spinning about an axis through its center and perpendicular to the plane of the disk differs from the moment of inertia of a disk spinning about an axis through its center in the plane of the disk.

The moment of inertia of an object depends on the mass of the object, and on how this mass is distributed with respect to the axis of rotation. The farther the bulk of the mass is from the axis of rotation, the greater is the rotational inertia (moment of inertia) of the object. The dimension of moment of inertia is mr^2 and its SI unit is $kg \times m^2$. We can calculate the moment of inertia of an object more easily by assuming it is divided into many small volume elements, each of mass Δm_i. We can then rewrite the expression for I in terms of Δm_i.

$$I = \lim_{\Delta m \to 0} \sum_i r_i^2 \Delta m_i = \int r^2 dm \tag{2.15}$$

Since $\rho = m/V$ (volumetric mass density), for the small volume segment $\rho = dm/dV$ or $dm = \rho dV$, then equation (2.15) becomes

$$I = \int r^2 dm = \int r^2 \rho dV \tag{2.16}$$

If ρ is constant, the integral can be evaluated with known geometry, otherwise its variation with position must be known.

Below are moments of inertia of some common ojects about their symmetrical axes which contain their centers of mass.

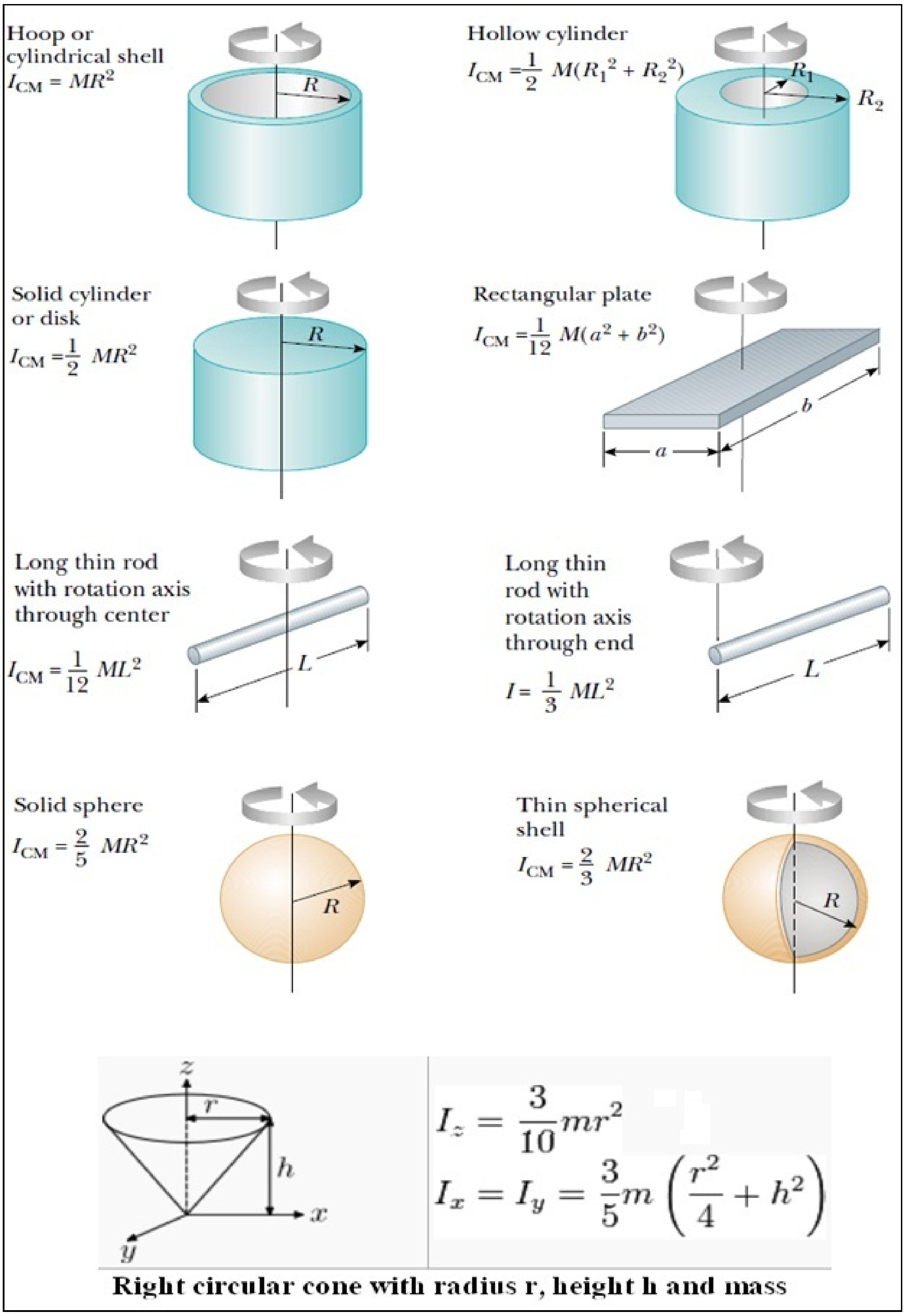

Figure 2.10: Moments of inertia of some common ojects about their symmetrical axes which contain their centers of mass

In classical mechanics, moment of inertia, also called **mass moment of inertia**, **rotational inertia**, **polar moment of inertia of mass**, or the **angular mass** is a measure of an object's resistance to changes to its rotation. It is the inertia of a rotating body with respect to its rotation. The moment of inertia plays much the same role in rotational dynamics as mass does in linear dynamics, describing the relationship between angular momentum and angular velocity, torque and angular acceleration, and several other quantities. The symbol **I** and sometimes **J** are usually used to refer to the moment of inertia or polar moment of inertia.

In this experiment, we determine moment of inertia by following mechanical system (see the figure 2.11). We assume that, the mass of the string and the frictions is necgleted. Applying the equation of Newton's second law for the hanging object, we have

$$P - T = ma \tag{2.17}$$

Here, **a** and **m** are the linear acceleration and the mass of the hanging object, respectively. T is tensional force and P is the gravitational force. And, from the equation of rotational dynamics, we obtain

$$TR = I\gamma \tag{2.18}$$

Where, **R** and γ are the radius and the angular acceleration of pulley, respectively. The relationship between a and are given by

$$\gamma = \frac{a}{R} \tag{2.19}$$

Putting (2.19) into (2.18) and after that combining (2.17), we obtain

$$I = \frac{m(g-a)R^2}{a} \tag{2.20}$$

Equation (2.20) show that, moment of inertia I value is determined when you know the value of accerlation a.

2.3.3 Instruments

(1) A hanging object (mass of m, shape of disk)
(2) A pulley (radius of R)
(3) Infrared interface (A' and B'
(4) Solid cylinder
(5) Cylinderical shell
(6) Solid sphere

(7) Switch box
(8) Electromagnetic
(9) A tripod
(10) A electronic time mea-suring device
(11) Connecting wires

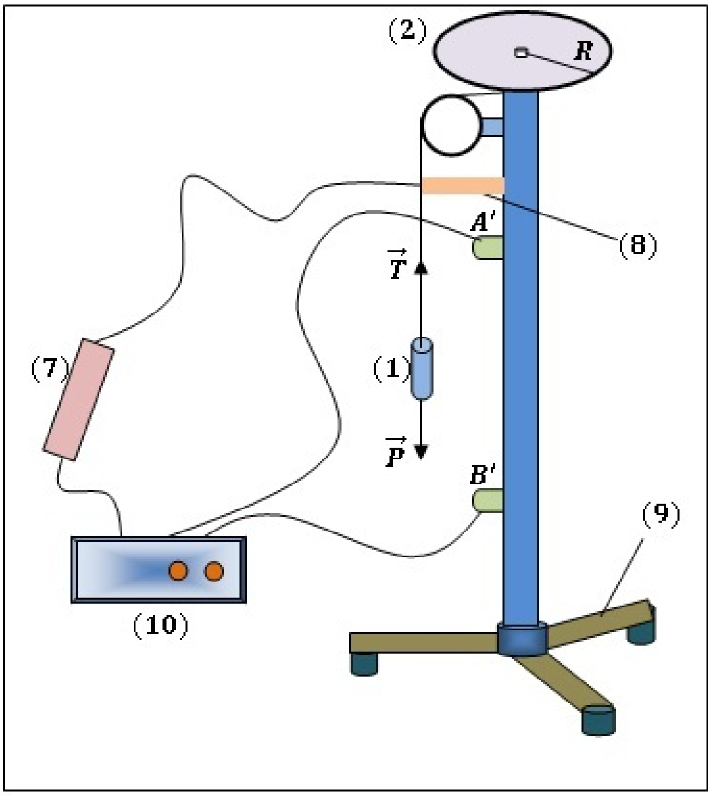

Figure 2.11: The dropping time interval of object (1) is determined by the device (10)

2.3.4 Procedure

Step 1: Attch the connecting head of the above infrared interface (A') to jack A and of the below infrared interface (B') to jack B. A and B are on the time-clock (A electronic time mea-suring device). Connecting one end of switch box to electromagnetic and another to time-clock. Adjust the control knob on the time-clock to mode $A \leftrightarrow B$ and the accuracy to 1/1000 second. Adjust the screws of the tripod so that the direction of plumb-line intersects the beam of rays of the above infrared interface. The above infrared interface is under the electromagnetic. The above and below infrared interface (A' and B') are separated by a distance 40cm. (A'B' = 40cm)
Step 2: Rotate the pulley to move hanging object to the position of the electromagnetic.

Note that, the lower surface of the hanging object and the beam of rays of the above infrared interface (A') are same high.

Step 3: Press the switch on the switch box and get the value of Δt which is the time interval for falling of hanging object from A' to B'. Calculate the value a, linear acceleration.

Step 4: Use the equation (2.20) to calculate I_{pulley}, the moment of inertia of pulley.

Step 5: Now, put the solid cylinder on the pulley and find the moment of inertia of system I (solid cylinder and pulley). After that, we find the moment of inertia of solid cylinder $I_{solidcylinder}$ by

$$I_{solidcylinder} = I - I_{pulley} \tag{2.21}$$

Repeat these above steps 5 times and put these values on the table 3.1 (see the reporting form of unit 3).

THE REPORTING FORM OF UNIT 3

(1) Question: Write the formula to calculate the value of linear acceleration, a, in terms Δt and S (here, S = A'B')

(2) Experiment's result: Finish the below data sheets and calculate the average values and corresponding errors.

Given:

The mass of the hanging object: $m = 0.0315 \pm 0.0001kg$

The radius of the pulley: $R = 0.0425 \pm 0.001m$

The gravitational acceleration: $g = 9.860 \pm 0.001m/s^2$

Calculate I_{pulley}, $\overline{I}_{pulley}$, $\overline{\Delta I}_{pulley}$

Measurment	Δt	**a**	Δa	I_{pulley}
1				
2				
3				
4				
5				
Average value				

Figure 2.12: Moment inertia of the pulley

Measurment	Δt	a	Δa	I_1
1				
2				
3				
4				
5				
Average value				

Figure 2.13: Moment of inertia of the system (solid cylinder + pulley)

Calculate I, I, $\overline{\Delta I}$

Calculate $I_{solidcylinder}$, the moment of inertia of the solid cylinder, with $\overline{I}_{solidcylinder} = \overline{I} - \overline{I}_{pulley}$ and $\overline{\Delta I}_{solidcylinder} = \overline{\Delta I} + \overline{\Delta I}_{pulley}$

2.4 Determining the period and gravitational acceleration by simple pendulum

2.4.1 The purposes of the experiment

- Understanding the experimental methods to determine the period of simple pendulum.
- Determining the gravitational acceleration from the value of period measured.

2.4.2 Theoretical backgrounds

The simple pendulum is another mechanical system that exhibits periodic motion.
It consists of a particle-like bob of mass **m** suspended by a light string of length **L** that is fixed at the upper end, as shown in Figure 2.13. The motion occurs in the vertical plane and is driven by the force of gravity. We shall show that, provided the angle ? is small (less than about 10^o), the motion is that of a **simple harmonic oscillator**. The forces

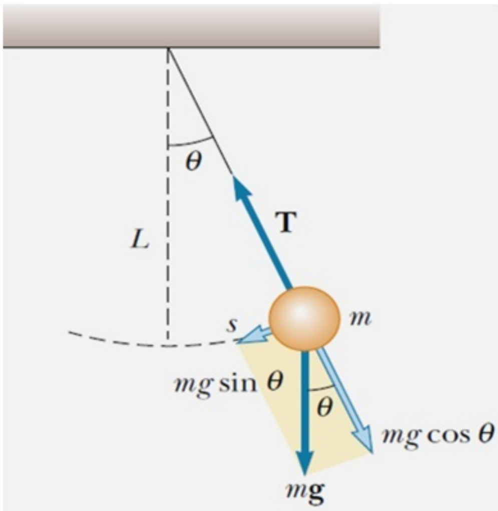

Figure 2.14: When θ is small, a simple pendulum oscillates in simple harmonic motion about the equilibrium position $\theta = 0$. The restoring force is $mgsin\theta$, the component of the gravitational force tangent to the arc.

acting on the bob are the force $\vec{T}$ exerted by the string and the gravitational force $m\vec{g}$. The tangential component of the gravitational force, $mgsin\theta$, always acts toward $\eta = 0$, opposite the displacement. Therefore, the tangential force is a restoring force, and we can apply Newton'second law for motion in the tangential direction:

$$\sum F_t = -mgsin\theta = m\frac{d^2s}{dt^2} \tag{2.22}$$

where s is the bobs displacement measured along the arc and the minus sign indicates that the tangential force acts toward the equilibrium (vertical) position. Because $s = L\theta$ and L is constant, this equation reduces to

$$\frac{d^2\theta}{dt^2} = -\frac{g}{L} sin\theta \tag{2.23}$$

we assume that θ is small, we can use the approximation $sin\theta \approx \theta$; thus the equation of motion for the simple penddulum becomes

$$\frac{d^2\theta}{dt^2} = -\frac{g}{L}\theta = \omega^2\theta \tag{2.24}$$

Equation 2.24 is second order linear differential equation and the solution of its is given by

$$\theta = \theta_{max} cos(\omega t + \varphi) \tag{2.25}$$

where θ_{max} the maximum angular displacement and the angular frequency ω is

$$\omega = \sqrt{\frac{g}{L}} \tag{2.26}$$

The period of the oscillation is

$$T = \frac{2\pi}{\omega} = 2\pi\frac{L}{g} \tag{2.27}$$

We also see that the period and frequency of a simple pendulum depend only on the length of the string and the acceleration due to gravity. Because the period is independent of the mass, we conclude that all simple pendulums that are of equal length and are at the same location (so that g is constant) oscillate with the same period.

The simple pendulum can be used as a timekeeper because its period depends only on its length and the local value of g. It is also a convenient device for making precise measurements of the free-fall acceleration. In fact, we can find the value of gravitational acceleration g if we measure the value of the period T

$$g = 4\pi^2\frac{L}{T^2} \tag{2.28}$$

2.4.3 Instruments

(1) A bracket has the height of 1m.
(2) A coil of thread
(3) A electronic time measuring device.
(4) A infrared interface
(5) A simple pendulum has the length of 0.4m.

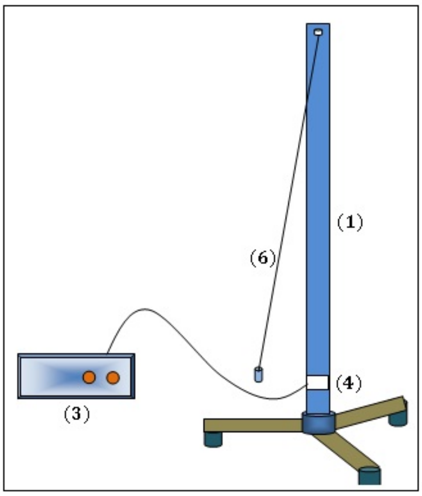

Figure 2.15: The device (3) determine time interval of oscillation of the hanging object.

2.4.4 Procedure

Step 1: Make a simple pendulum: The string has the leghth of $0.4m$ and $\theta_{max} < 10^o$. Note that, you have to adjust the srews on the tripod so that the direction of the string is vertical when the hanging object is at equilibrium point.
Step 2: Measure the time interval Δt, time interval of 20 periods.
Step 3: Calculate the period T and gravitational acceleration g. (see the reporting form of unit 4)

THE REPORTING FORM OF UNIT 4

(1) Question: If you replace the hanging object of simple pedulum, will the period be changed to other value? If not, explain its!
(2) Experiment's result: Finish the below data sheet and calculate the average values and corresponding error.

Given

The length of the simple pendulum: $L = 0.400 \pm 0.001 m$
The angular amplitude: $\theta_{max} < 10^o$
Pi number: $\pi = 3.1416 \pm 0.0001$
The intrusmental error of the electronic time measuring device: $0.01 second$
The gravitational acceleration: $g = \bar{g} \pm \overline{\Delta g}$

measurment	$t = 20T$	T	ΔT	g
1				
2				
3				
4				
5				
The average value				

Figure 2.16: The value of time interval and corresponding gravitational acceleration

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