Hanoi University of Science and Technology (HUST)

Faculty of Engineering Physics (FEP)

PHYSICS LABWORK

For PH1016
(New version)

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Experiment 1

MEASUREMENT OF BASIC LENGTH

Instruments

1. Vernier caliper;
2. Micrometer.

1. VERNIER CALIPER

1.1 Introduction

The Vernier Caliper is a precision instrument that can be used to measure internal and external distances extremely accurately. The details of a vernier principle are shown in Fig.1. An ordinary vernier caliper has jaws you can place around an object, and on the other side jaws made to fit inside an object. These secondary jaws are for measuring the inside diameter of an object. Also, a stiff bar extends from the caliper as you open it that can be used to measure depth. The accuracy which can be achieved is proportional to the graduation of the vernier scale.

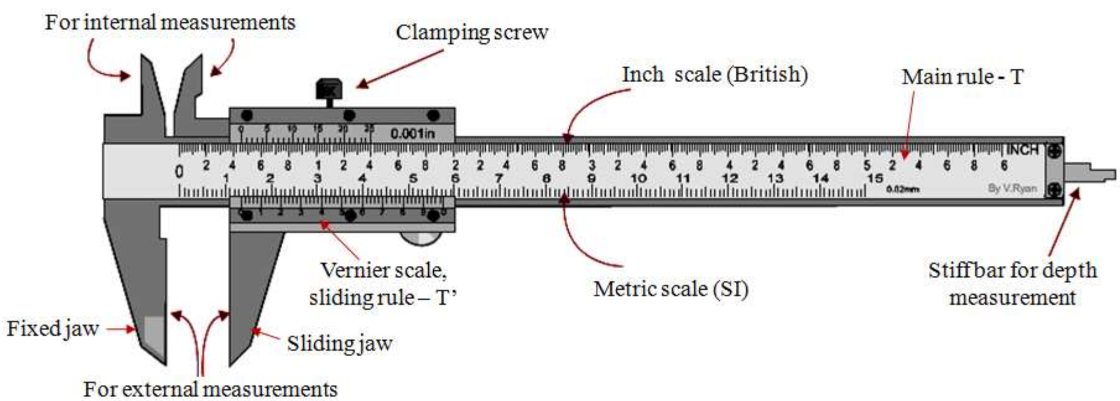


***Fig.1**. Structure of an ordinary vernier caliper*

When the jaws are closed, the vernier zero mark coincides with the zero mark on the scale of the rule. The vernier scale (T') slides along the main rule (T). The main rule allows you to determine the integer part of measured value. The sliding rule is provided with a small scale which is divided into equal divisions. It allows you to determine the decimal part of measured result in combination with the caliper precision (Δ), which is calculated as follows:

$$\Delta = \frac{1}{N} \tag{1}$$

Where, N is the number of divisions on vernier scale (except the 0-mark), then, for $N = 10$ we have $\Delta = 0.1$ mm, $N = 20$ we have $\Delta = 0.05$ mm, and $N = 50$ we have $\Delta = 0.02$ mm.

1.2 How to use a vernier caliper

- Preparation to take the measurement, loosen the locking screw and move the slider to check if the vernier scale works properly. Before measuring, do make sure the caliper reads 0 when fully closed.

- Close the jaws lightly on the item which you want to measure. If you are measuring something round, be sure the axis of the part is perpendicular to the caliper. In other words, make sure you are measuring the full diameter.

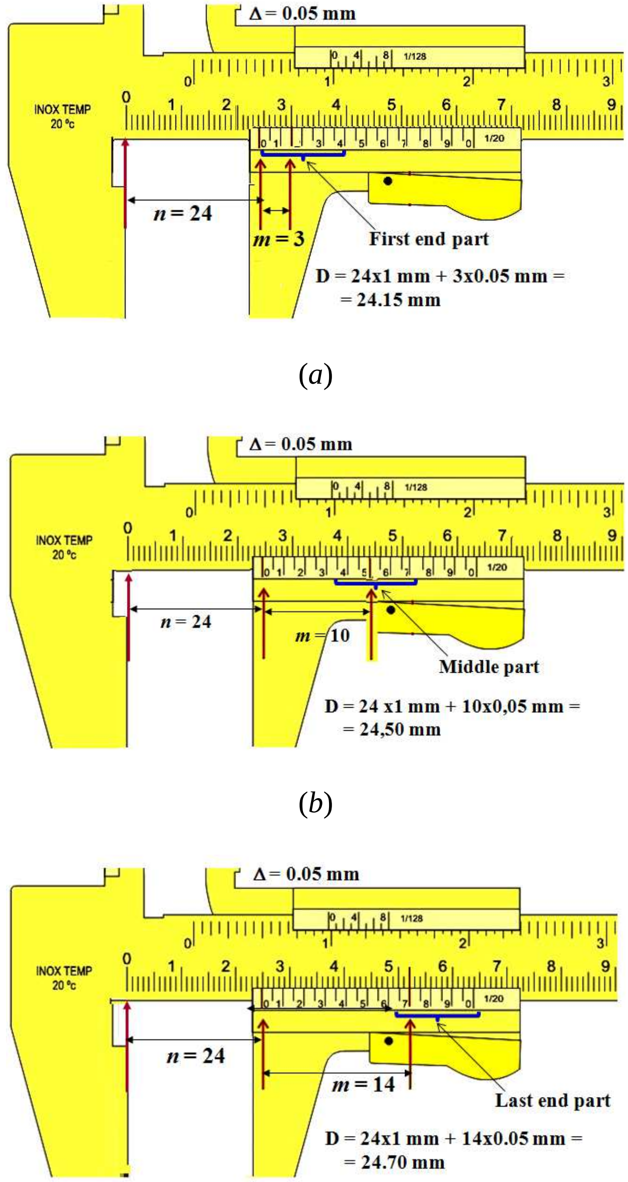
1.3 How to read a vernier caliper

In order to determine the measurement result with a vernier caliper, you can use the following equation:

$$D = n\,a + m\,\Delta \qquad (2)$$

Where, a is the value of a division on main rule (in millimeter), i.e., a = 1 mm, Δ is the vernier precision and also corresponding to the value of a division on sliding rule that you can either find it on the caliper body or determine it's value using the eq. (1).

- ***Step 1***: Count the number of division (n) on the main rule – T, lying to the left of the 0-mark on the vernier scale – T' (see example in Fig. 2)
- ***Step 2***: Look along the division mark on vernier scale and the millimeter marks on the adjacent main rule, until you find the two that most nearly line up. Then, count the number of divisions (m) on the vernier scale except the 0-mark (see example in Fig. 2).
- ***Step 3***: Put the obtained values of n and m into eq. (2) to calculate the measured dimension as shown in Fig.2.



(c)

Fig.2. *Method to read vernier caliper*

<u>Attention</u>:

The Vernier scale can be divided into three parts called first end part, middle part, and last end part as illustrated in Fig. 2a, 2b, and 2c, respectively.

+ If the 0-mark on vernier scale is just adjacently behind the division n on the main rule, the division m should be on the first end part of vernier scale (see example in Fig.2a).

+ If the 0-mark on vernier scale is in between the division n and $n+1$ on the main rule, the division m should be on the middle part of vernier scale (see example in Fig.2b).

+ If the 0-mark on vernier scale is just adjacently before the division $n+1$ on the main rule, the division m should be on the last end part of vernier scale (see example in Fig.2c).

II MICROMETER

2.1 Introduction

The micrometer is a device incorporating a calibrated screw used widely for precise measurement of small distances in mechanical engineering and machining. The details of a micrometer principle are shown in Fig.3. Each revolution of the rachet moves the spindle face 0.5mm towards the anvil face. A longitudinal line on the frame (called referent one) divides the main rule into two parts: top and bottom half that is graduated with alternate 0.5

millimeter divisions. Therefore, the main rule is also called “double one”. The thimble has 50 graduations, each being 0.01 millimeter (one-hundredth of a millimeter). It means that the precision (Δ) of micrometer has the value of 0.01. Thus, the reading is given by the number of millimeter divisions visible on the scale of the sleeve plus the particular division on the thimble which coincides with the axial line on the sleeve.

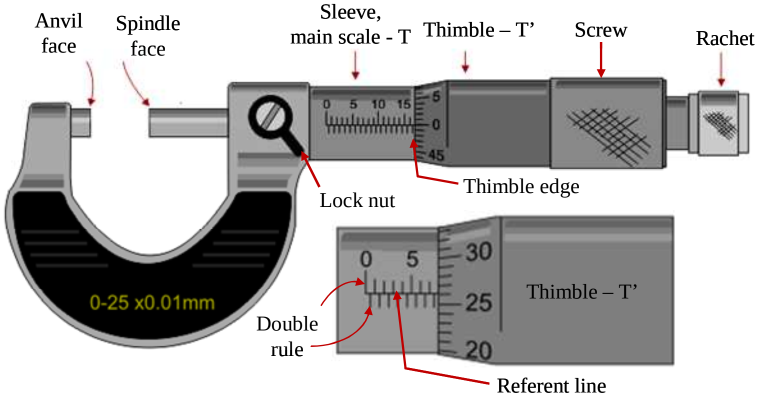


Fig.3. *Structure of an ordinary micrometer*

2.2 How to use a micrometer

- Start by verifying zero with the jaws closed. Turn the ratcheting knob on the end till it clicks. If it isn't zero, adjust it.
- Carefully open jaws using the thumb screw. Place the measured object between the anvil and spindle face, then turn ratchet knob clockwise to the close the around the specimen till it clicks. This means that the ratchet cannot be tightened any more and the measurement result can be read.

2.3 How to read a micrometer

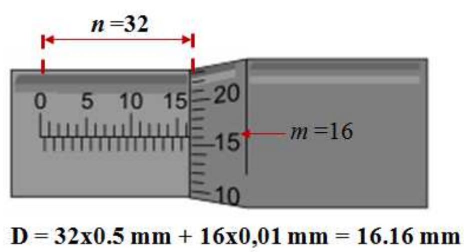
In order to determine the measurement result with a micrometer, you can also use the following equation:

$$D = n\,a + m\,\Delta \tag{3}$$

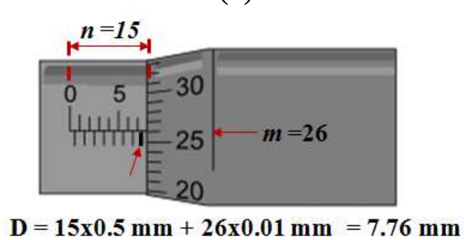
Where, a is the value of a division on sleeve - double rule (in millimeter), i.e., a = 0.5 mm, Δ is the micrometer’s precision and also corresponding to the value of a division on thimble (usually Δ = *0.01* mm).

- ***Step 1***: Count the number of division (n) on the sleeve - T of both the top and down divisions of the double rule lying to the left of the thimble edge.
- ***Step 2***: Look at the thimble divisions mark – T’ to find the one that coincides nearly a line with the referent one. Then, count the number of divisions (m) on the thimble except the 0-mark
- ***Step 3***: Put the obtained values of n and m into eq. (3) to calculate the measured dimension as the examples shown in Fig.4.

Please read carefully the following note when performing the measurement.



(*a*)



(*b*)

Fig. 4. *Method to read micrometer*

*.**Attention***:

The ratchet is only considered to spin completely a revolution around the sleeve when the 0-mark on the thimble passes the referent line. As an example shown in Fig.5, it seems that you can read the value of *n* as 6, however, due to the 0-mark on the thimble lies above the referent line, then this parameter is determined as 5.

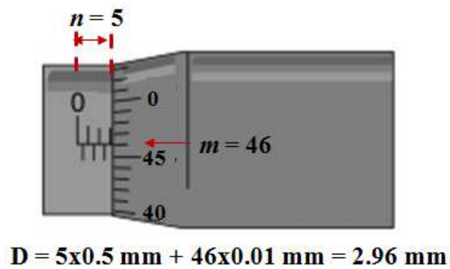


Fig.5. *Ratchet does not spin completely a revolution around the sleeve, yet.*

III. EXPERIMENTAL PROCEDURE

1. Use the Vernier caliper to measure the external and internal diameter (D and d respectively), and the height (h), of a metal hollow cylinder (Fig.6) based on the method of using and reading this rule presented in part 1.2 and 1.3.

Note: do 5 trials for each parameter.

2. Use the micrometer to measure the diameter (D_b) of a small steel ball for 5 trials based on the method of using and reading this device presented in part 2.2 and 2.3.

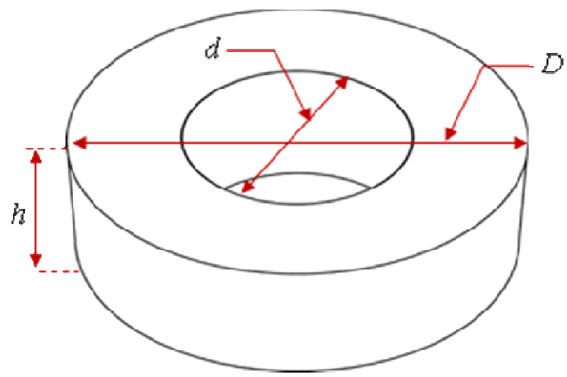


Fig.6. *Metal hollow cylinder for measurement*

IV. LAB REPORT

Your lab report should include the following issues:

1. A data sheet with one data table of the measurement results for the height (h), external (D) and internal (d) diameter of metal hollow cylinder, and one data table of the measurement results for the diameter (D_b) of small steel ball.

2. Calculate the volume and density of the metal hollow cylinder using the following equations:

$$\overline{V} = \frac{\pi}{4}\left(\overline{D}^2 - \overline{d}^2\right)\overline{h} \quad (5)$$

$$\overline{\rho} = \frac{m}{\overline{V}} \quad (6)$$

3. Determine uncertainties and report the last result of those quantities in the form like $V = \overline{V} \pm \Delta V$

4. Calculate the volume of the steel ball using the following equation:

$$\overline{V_b} = \frac{1}{6}\pi\overline{D_b}^3 \quad (7).$$

5. Determine uncertainty and report the last result of this quantity.

6. ***Note***: Please read the instruction of "***Significant Figures***" on page 6 of the document "***Theory of Uncertainty***" to know the way for reporting the last result.

Experiment 2

MOMENTUM AND KINETIC ENERGY IN ELASTIC AND INELASTIC COLLISION

Equipment:
1. Aluminum demonstration track;
2. Starter system for demonstration track;
3. End holder for demonstration track
4. Light barrier (photo-gate)
5. Cart having low friction sapphire bearings;
6. Digital timers with 4 channels;
7. Trigger.

I. THEORETICAL BACKGROUND

1. Momentum and conservation of momentum

Momentum is a physics quantity defined as product of the particle's mass and velocity. It is a vector quantity with the same direction as the particle's velocity.

$$\vec{p} = m\vec{v} \tag{1}$$

Then we may demonstrate the Newton's second law as

$$\Sigma\vec{F} = \frac{d\vec{p}}{dt} \tag{2}$$

The concept of momentum is particularly important in situations in which we have two or more interacting bodies. For any system, the forces that the particles of the system exert on each other are called internal forces. Forces exerted on any part of the system by some object outside it are called external forces. For the system, the internal forces are cancelled due to the Newton’s third law. Then, if the vector sum of the external forces is zero, the time rate of change of the total momentum is zero. Hence, the total momentum of the system is constant:

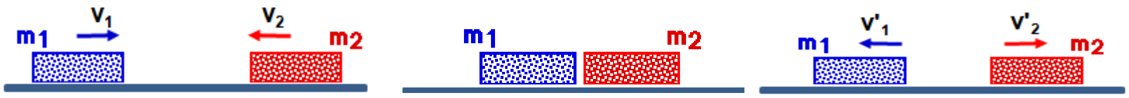
$$\Sigma\vec{F} = 0 = \frac{d\vec{p}}{dt} \Rightarrow \vec{p} = const \tag{3}$$

This result is called the principle of conservation of momentum.

2. Elastic and inelastic collision

2.1 Elastic collision

If the forces between the bodies are much larger than any external forces, as is the case in most collisions, we can neglect the external forces entirely and treat the bodies as an isolated system. The momentum of an individual object may change, but the total for the system does not. Then momentum is conserved and the total momentum of the system has the same value before and after the collision. If the forces between the bodies are also conservative, so that no mechanical energy is lost or gained in the collision, the total kinetic energy of the system is the same after the collision as before. *Such a collision is called an elastic collision.* This case can be illustrated by an example in which two bodies undergoing a collision on a frictionless surface as shown in Fig.1.



(a) (b) (c)

Fig. 1. *Before collision (a), elastic collision (b) and after collision (c)*

Remember this rule:

- In any collision in which external forces can be neglected, momentum is conserved and the total momentum before equals the total momentum after that is

$$m_1\vec{v}_1{}' + m_2\vec{v}_2{}' = m_1\vec{v}_1 + m_2\vec{v}_2 \tag{4}$$

- In elastic collisions only, the total kinetic energy before equals the total kinetic energy after that is

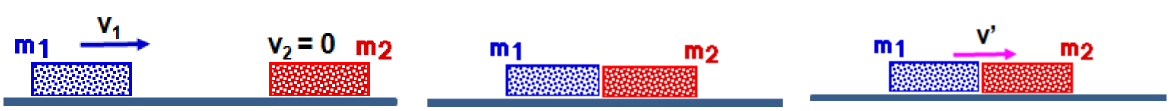
$$\frac{1}{2}m_1v'^2_1 + \frac{1}{2}m_1v'^2_2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_1v_2^2 \tag{5}$$

If the second body is in stationary ($v_2 = 0$) then taking the vector eq. (4) along the direction from left to right, results in

$$-m_1v'_1 + m_2v'_2 = m_1v_1 \tag{6}$$

2.2 Inelastic collision

A collision in which the total kinetic energy after the collision is less than before the collision is called an inelastic collision. An inelastic collision in which the colliding bodies stick together and move as one body after the collision is often called a completely inelastic collision. The phenomenon is represented in Fig.2.



(a) (b) (c)

Fig. 2. *Before collision (a), completely inelastic collision (b) and after collision (c)*

Conservation of momentum gives the relationship:

$$m_1\vec{v}_1 + m_1\vec{v}_2 = (m_1 + m_2)\vec{v}' \tag{7}$$

In the case that the second mass is initially at rest ($v_2 = 0$) then taking the vector eq. (9) along the direction from left to right, results in

$$m_1v = (m_1 + m_2)v' \tag{8}$$

Let's verify that the total kinetic energy after this completely inelastic collision is less than before the collision. The motion is purely along the x-axis, so the kinetic energies K_E and K'_E before and after the collision, respectively, are:

$$K = \frac{1}{2}m_1v^2 \tag{9}$$

$$K' = \frac{1}{2}(m_1 + m_2)v'^2 = \frac{1}{2}(m_1 + m_2)\left(\frac{m_1}{m_1 + m_2}\right)^2 v \tag{10}$$

Then, the ratio of final to initial kinetic energy is

$$\frac{K'}{K} = \frac{m_1}{m_1 + m_2} \tag{11}$$

It is obviously that the kinetic energy after a completely inelastic collision is always less than before.

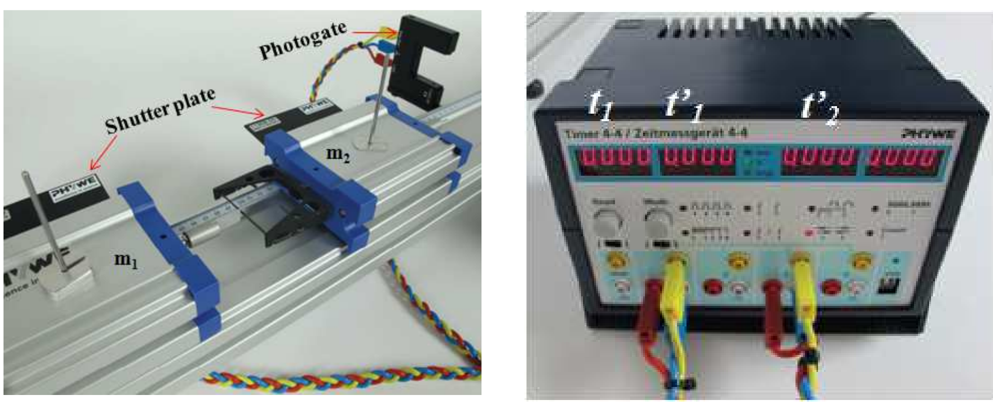
II. EXPERIMENTAL PROCEDURE

2.1 Set up the measurement

In this experiment, the collisions between two carts attached with <u>"shutter plate" (length as 100 mm</u>) (Fig. 3a) will be investigated. One end of cart 1 is attached with a magnet with a plug facing the starter system and the other one is attached with a plug in the direction of motion. The duration that the carts go through the photogates before and after the collisions will be measured by the timer (Fig. 3b) that enables to calculate the corresponding velocities.

2.2 Investigation of elastic collision

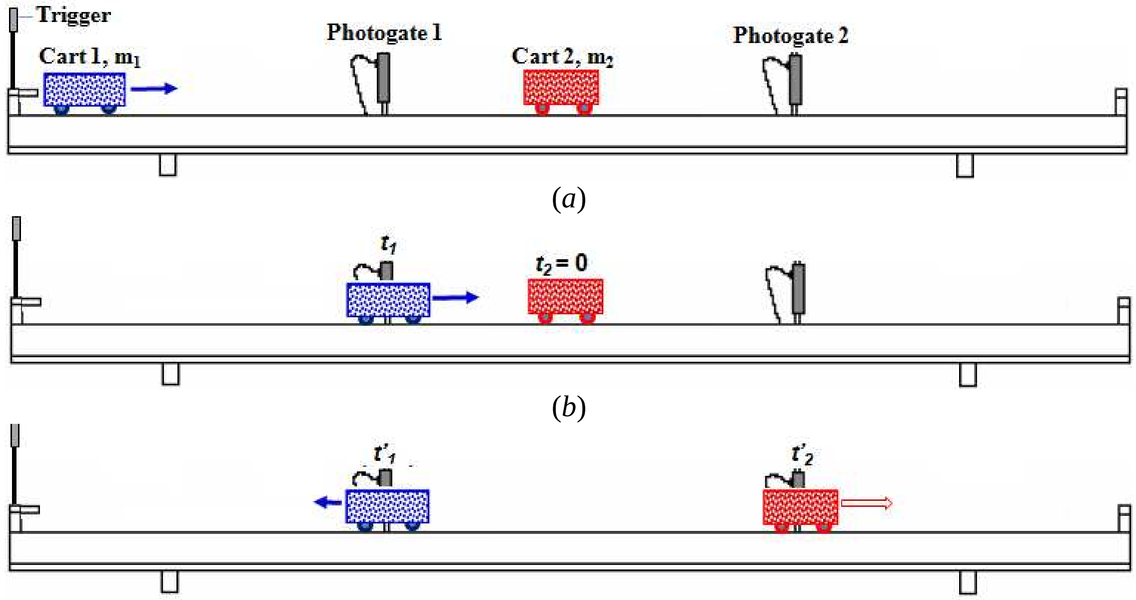
- ***Step 1***: Place the cart 1 (m_1) on the left of track closer to the starter system. The cart m_2 is stationary between the photogates. It means that its initial velocity v_2 = 0. In this investigation, cart 2 is attached with a bow-shaped fork with rubber band facing cart 1 and a needle plug facing the end holder on the right of track (Fig. 4a). The photogate 1 should be located at position of 50 cm and photogate 2 at 100 cm. <u>It is also noted that</u> in this case, <u>the weight m_1 should be haft of m_2</u> due to cart 2 is attached with an additional weight (400 g).
- ***Step 2***: Push the trigger on the top of vertically long stem of the starter system that enables cart 1 to be released and accelerate in the direction to cart 2 (initially in stationary that is v_2 = 0). During this process, it receives an initial velocity v_1 that can be calculated by the duration $\boldsymbol{t_1}$ when it goes through the photogate 1 corresponding to the shutter plate's length. .



(*a*) (*b*)

Fig. 3. *Carts enclosed with shutter plates (a) and the timer for investigating the collision (b)*

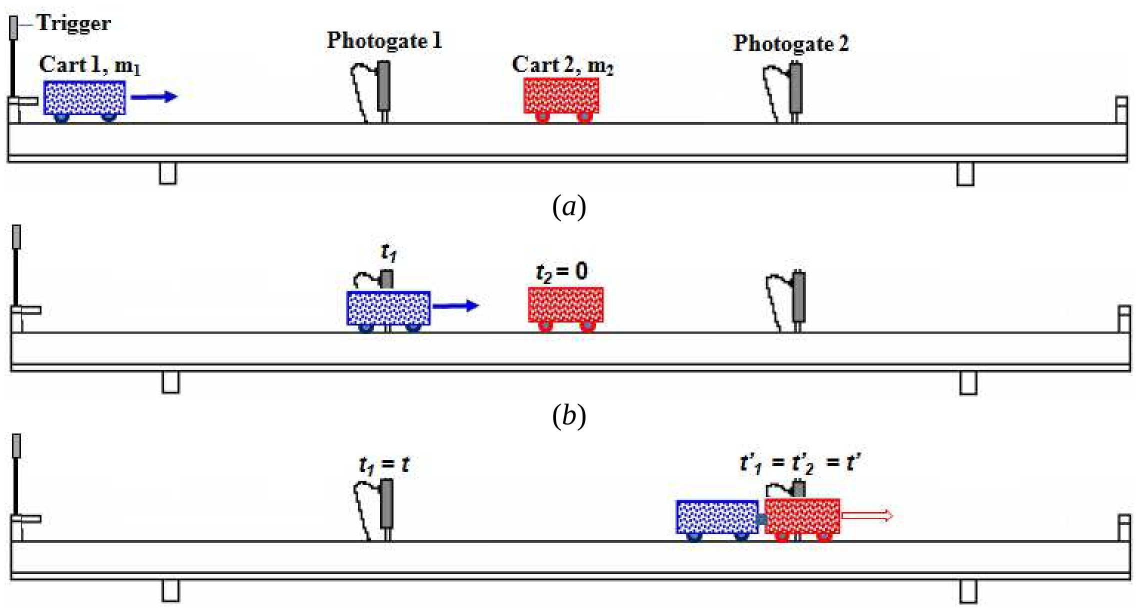
- ***Step 3***: After collision, cart 2 moves with the velocity v'_2 that can be calculated by the using the duration $\boldsymbol{t'_2}$ measured by photogate 2 and cart 1 goes back (Fig. 4c). Record the time $\boldsymbol{t_1}$, $\boldsymbol{t'_1}$ and $\boldsymbol{t'_2}$ displayed on the corresponding windows of timer as shown in Fig. 3b.
- ***Step 4***: Repeat the measurement procedure from step 1 to 3 for more 9 times and record all the measurement results in a data sheet 1.
- ***Step 5***: Weight two carts to know their masses by using an electronic balance. Record the mass of each cart on data sheet.



(*c*)
Fig.4. *Experimental procedure to investigate the elastic collision*

2.3 Investigation of inelastic collision

- ***Step 1***: Place the cart 1 (m_1) on the left of track closer to the starter system. Put off the right plug of cart 1 and attach the other one with a needle facing to cart 2 (Fig. 5a). Place the cart 2 (m_2) also stationary between the photogates as in Part 2.2. In this circumstance, the fork plug facing cart 1 is replaced by another one having plasticine. <u>It is noted that</u> in this case, <u>the weight m_1 should be twice m_2</u>. In order to get this condition, <u>take off the additional weight from cart 2 and put it on cart 1.</u>



(*c*)
Fig.5. *Experimental procedure to investigate the inelastic collision*

- ***Step 2***: Push the trigger of the starter system that enables cart 1 to be released and accelerate in the direction to cart 2 similar previous case. Record the moving time $\boldsymbol{t_1}$ that can be considered as $\boldsymbol{t}$ (Fig. 5b).

- ***Step 3***: After collision, cart 1 sticks with cart 2 then both carts move together with the same velocity *v'* that can be calculated by the duration $\boldsymbol{t'_1 = t'_2 = t'}$ measured by photogate 2. Record the ***t'*** displayed on the timer (Fig. 5c).
- ***Step 4***: Repeat the measurement procedure from step 1 to 3 for more 9 times and record all the measurement results in a data sheet 2.
- ***Step 5***: Weight two carts to know their masses by using an electronic balance. Record the mass of each cart.

III. LAB REPORT

Your lab report should include the following content:

1. A data sheet with the recorded values of times before and after the collision (should be 10 trials) as well as masses of two carts for both cases of elastic and inelastic collision (with two separate data tables).
2. Check the conversation of momentum and kinetic energy before and after the collision in the elastic collision. In this case, based on the given and measured data we have

$$p = m_1 \frac{\ell}{t_1} \text{ and } p' = -m_1 \frac{\ell}{t'_1} + m_2 \frac{\ell}{t'_2}$$

$$K_E = \frac{1}{2} m_1 \left(\frac{\ell}{t_1}\right)^2 \text{ and } K'_E = \frac{1}{2} m_1 \left(\frac{\ell}{t'_1}\right)^2 + \frac{1}{2} m_2 \left(\frac{\ell}{t'_2}\right)$$

Where ℓ is the length of the shutter plate.

Do calculation of the uncertainties in the momentum and kinetic energy before and after collision for each case. Make the conclusions of the obtained results.

3. Calculate the momentums and kinetic energies before and after the collision in the inelastic collision. In this case, based on the given and measured data we have

$$p = m_1 \frac{\ell}{t} \text{ and } p' = (m_1 + m_2) \frac{\ell}{t'}$$

$$K_E = \frac{1}{2} m_1 \left(\frac{\ell}{t}\right)^2 \text{ and } K'_E = \frac{1}{2} (m_1 + m_2) \left(\frac{\ell}{t'}\right)^2$$

Where ℓ is the length of the shutter plate.

Do calculation of the uncertainties for the momentum and kinetic energy before and after collision for each case. Make the conclusions of the obtained results.

4. Evaluation of the percent changes in kinetic energy (K_E) through the elastic and inelastic collision (using eq. 11). Make the conclusions of the obtained results.

Note: The collision is not completely elastic because there is still some residual friction when the carts move. That's why the total momentum may decrease slightly by approximately 6 % and the kinetic energy may decrease up to 25 %.

5. ***Note***: Please read the instruction of "***Significant Figures***" on page 6 of the document "***Theory of Uncertainty***" to know the way for reporting the last result.

Experiment 3

MOMENT OF INERTIA OF THE SYMMETRIC RIGID BODIES

I. THEORETICAL BACKGROUND

It is known that the moment of inertia of the body about the axis of rotation is determined by

$$I = \int r^2 dm \tag{1}$$

Where *dm* is the mass element and *r* is the distance from the mass element to the axis of rotation. In the m.k.s. system of units, the units of *I* are kgm^2/s.

If the axis of rotation is chosen to be through the center of mass of the object, then the moment of inertia about the center of mass axis is call I_{cm}. In case of the typical symmetric and homogenous rigid bodies, I_{cm}.is calculated as follows

- For a long bar: $I_{cm} = \frac{1}{12} ml^2$ (2)

- For a thin disk or a solid cylinder: $I_{cm} = \frac{1}{2} mR^2$ (3)

- For a hollow cylinder having very thin wall: $I_{cm} = mR^2$ (4)

- For a solid sphere: $I_{cm} = \frac{2}{5} mR^2$ (5)

The parallel-axis theorem relates the moment of inertia Icm about an axis through the center of mass to the moment of inertia I about a parallel axis through some other point. The theorem states that,

$$I = I_{cm} + Md^2 \tag{6}$$

This implies I_{cm} is always less than *I* about any other axis.

In this experiment, the moment of inertia of a rigid body will be determined by using an apparatus which consists of a spiral spring (made of brass). The object whose moment of inertia is to be measured can be mounted on the axis of this torsion spring which tends to restrict the rotary motion of the object and provides a restoring torque. If the object is rotated by an angle ϕ, the torque acting on it will be

$$\tau_z = D_z..\phi \tag{7}$$

where D_z. is a elastic constant of spring.

This torque will make the object oscillation. Using the theorem of angular momentum of a rigide body in rotary motion.

$$\tau = \frac{dL}{dt} = I\frac{d\omega}{dt} = I\frac{d^2\phi}{dt^2} \tag{8}$$

We get the typical equation of oscillation as

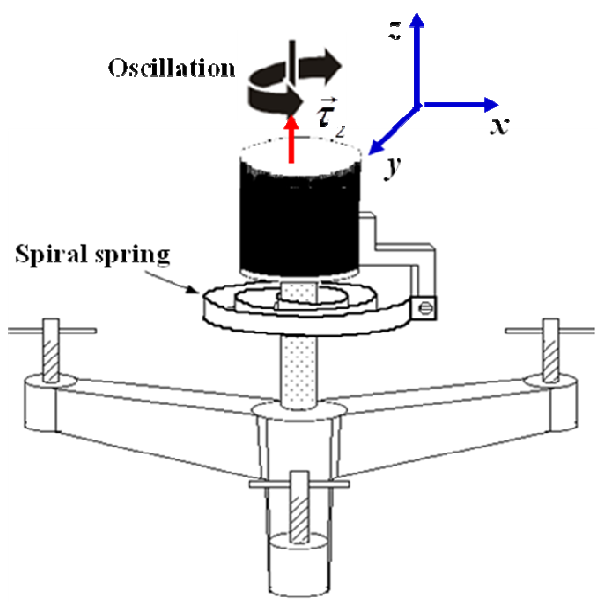


Fig. 1. *Experimental model to determine the moment of inertia of the rigid body*

$$\frac{d^2\phi}{dt^2} + \frac{D_z}{I}\phi = 0 \tag{9}$$

The oscillation is corresponds to a period

$$T = 2\pi\sqrt{\frac{I}{D_z}} \tag{10}$$

According to (10), for a known D_z, the unknown moment of inertia of an object can be found if the period T is measured.

II. EQUIPMENT

1. Rotation axle with spiral spring having the elastic constant, D_z = 0,044 *Nm/Rad*;
2. Light barrier (or photogate) with counter;
3. Rod with length of 620mm and mass of 240g;
4. Solid sphere with mass of 2290g and diameter of 146mm;
5. Solid disk with mass of 795g and diameter of 220mm;
6. Hollow cylinder with mass of 780g and diameter of 89mm;
7. Supported thin disk;
8. A set of screws for mounting the objects;
9. Tripod base.

***Fig. 2**. Equipments for measurment*

III. EXPERIMENTAL PROCEDURE

3. 1. Measurement of the rod

- ***Step 1:*** Equipment is setup corresponding to Fig.3. A mask (width ~ 3 mm) is stuck on the rod to ensure the rod went through the photogate.
- ***Step 2:*** Press the button "Start" to turn on the counter. Then, you can see the light of LED on the photogate.
- ***Step 3:*** Push the rod to rotate with an angle of 180^0, then let it to oscillate freely. The time of a vibration period of the rod will be measured. In this case, the result you got is averaged after several periods. Make 5 trials and record the measurement result of period T in a data sheet.

***Fig. 3**. Experimental setup for measurement of the rod*

- ***Step 4:*** Press the button "Reset" to turn the display of the counter being 0. Uninstall the rod for next measurement.

3.2 Measurement of the solid disk

- Using the suitable screws to mount the solid disk on the rotation axle of the spiral spring as shown in Fig.4. A piece of note paper is stuck on the disk to ensure it passing through the photogate.

- Perform the measurement procedure similar to that of the rod. Record the measurement result of period T in a data sheet.

- Press the button "Reset" to turn the display of the counter being 0. Uninstall the disk for next measurement.

Fig. 4. *Experimental setup for measurement of the solid disk*

3.3 Measurement of the hollow cylinder

- Using the suitable screws to mount the hollow cylinder coupled with a supported disk below on the rotation axle of the spiral spring as shown in Fig.5. A piece of note paper is also stuck on the disk to ensure the system passing through the photogate.

- Perform the measurement procedure similar to that of the disk. Record the measurement result of period T (5 trials) in a data sheet.

- Push the button "Reset" to turn the display of the counter being 0. Uninstall the hollow cylinder and repeat the measurment to get its rotary period T (5 trials) ..

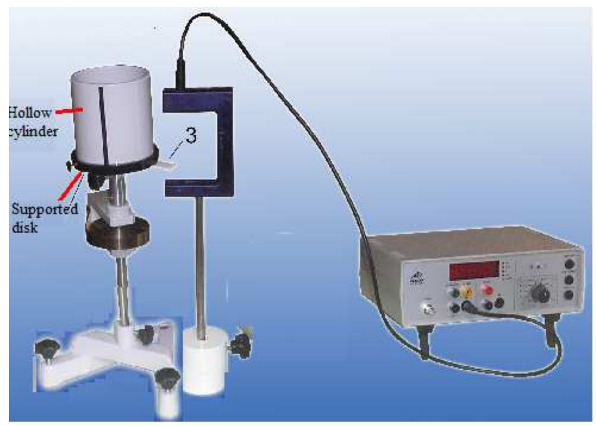


Fig. 5. *Experimental setup for measurement of the hollow cylinder*

- Press the button "Reset" to turn the display of the counter being 0. Uninstall the supported disk for next measurement.

3.4 Measurement of the Solid Sphere

- Mount the solid sphere on the rotation axle of the spiral spring as shown in Fig.6. A piece of note paper is also stuck on the sphere to ensure its passing through the photogate.

- Push the sphere to rotate with an angle of 270^0, then let it to oscillate freely. The obtained vibration period of the sphere will be recorded (5 trials) in the data sheet.

- Uninstall the solid sphere and switch off the counter to finish the measurements.

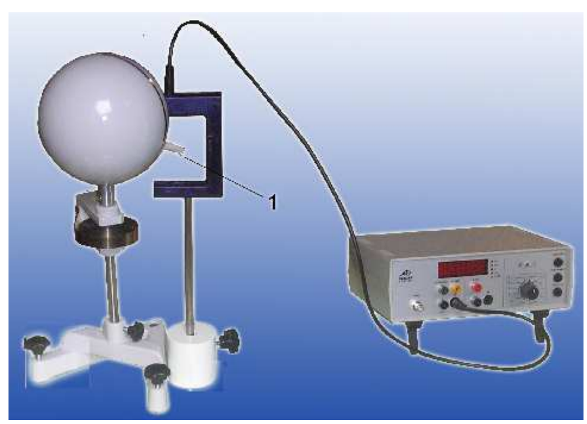


Fig. 6. *Experimental setup for measurement of the solid sphere*

III. LAB REPORT

Your lab report should include:
1. A data sheet of the vibration periods of the measured rigid bodies.
2. Determine the average value of the vibration periods of corresponding bodies and then calculate the moment of inertia of the rod, solid disk, and solid sphere using equation (10).
3. The moment of inertia of the hollow cylinder is calculated by subtracting that of alone supported disk from the coupled object (consisting of the cylinder and supported disk).
4. Calculate the uncertainty of the moment of inertia obtained by experiment.
5. Calculate the value of moment of inertia of the rigid bodies based on the theoretical formula (2 to 5) and compare them to the measured values. Note that you use the relatively difference as an estimate of the errors.
6. ***Note***: Please read the instruction of "***Significant Figures***" on page 6 of the document "***Theory of Uncertainty***" to know the way for reporting the last result.

Experiment 4

DETERMINATION OF GRAVITATIONAL ACCELERATION USING SIMPLE PENDULUM OSCILLATION WITH PC INTERFACE

Principle and task

Earth's gravitational acceleration g is determined for different lengths of the pendulum by means of the oscillating period. If the oscillating plane of the pendulum is not parallel to the gravitational field of the earth, only one component of the gravitational force acts on the pendulum movement.

I. BACKGROUND

As a good approximation, the pendulum used here can be treated as a mathematical (simple) one having mass *m* and a length l. When pendulum mass *m* is deviated to a small angle γ, a retracting force acts on it to the initial balanced position (Fig.1):

$$F(\gamma) = -mg \cdot \sin\gamma \approx -mg.\gamma \quad (1)$$

If one ensures that the amplitudes remain sufficiently small while experimenting, the movement can be described by the following differential equation:

$$I\frac{d^2\gamma}{dt^2} = -g\gamma \quad (2)$$

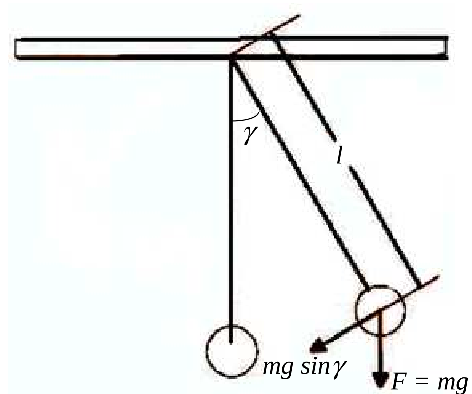


Fig. 1. *Pendulum with vertical oscillation plane*

The solution of eq.(2) can be written as follows:

$$\gamma = \gamma_0 \sin\left(\sqrt{\frac{l}{g}}\,.\,t\right) \quad (3)$$

This is a harmonic oscillation having the amplitude γ_0 and the oscillation period *T*.

$$T = 2\pi\,.\sqrt{\frac{l}{g}} \quad (4)$$

If one rotates the oscillation plane around the angle θ with respect to the vertical plane as shown in Fig.2, the components of the acceleration of gravity $g(\theta)$ which are effective in its oscillation plane are reduced to $g(\theta) = g.\cos\theta$, that is only the force component $mg.\sin\gamma.\cos\theta$ is effective and the following is obtained for the oscillation period:

$$T = 2\pi\,.\sqrt{\frac{l}{g\cos\theta}} \quad (5)$$

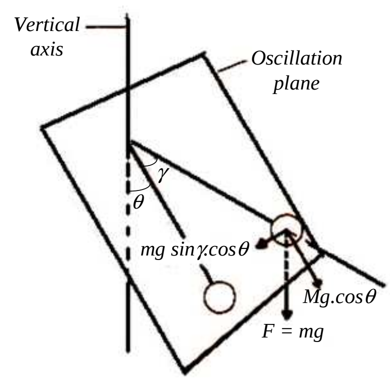


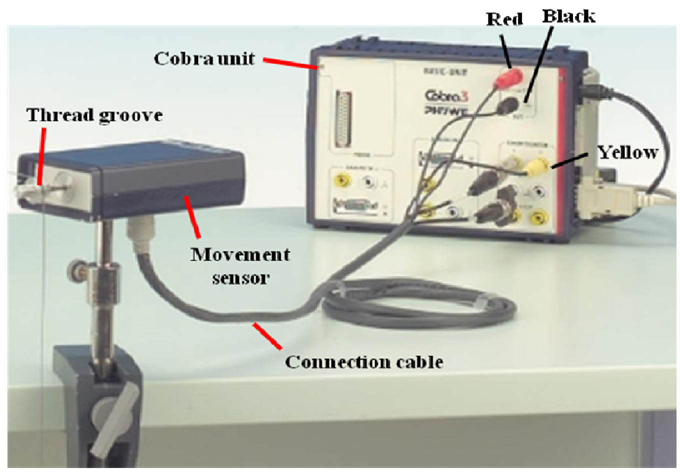
Fig. 2. *Pendulum with inclined oscillation plane*

In this experiment you will perform the investigation of the harmonic oscillation of mathematical pendulum in two cases to see how the gravitational acceleration depends on its length and the inclined angle based on equation (4) and (5).

II. II. EXPERIMENTAL PROCEDURE

2.1 Cobra Interface

The Cobra3-Basic-Unit is an interface for measuring, controlling and regulating in physics and technology. It can be operated with a computer using serial USB interface and suitable software corresponding to the certain sensor. In this case it is translation/rotation recorder. All functional and operating elements are on the front plate or on the side walls of the instrument as can be seen in Fig. 3a. The electric connection of the movement sensor is carried out according to Fig. 3b for the COBRA interface. The thread runs horizontally and is lead past the larger of the two thread grooves of the movement recorder.



(*a*) (*b*)

Fig. 3. *COBRA3 interface (a) and electric connections for movement recorder (b)*

2.2. Pendulum with vertical oscillation plan

2.2.1. Preparation

- Set up the experiment according to Fig. 4 such that the oscillating plane runs vertically.
- Start the MEASURE software written for COBRA interface. The COBRA window is appeared for setting measuring parameters according to Fig. 5. The diameter of the thread groove of the movement recorder is entered into the input window d_0 (12 mm are set as a default value). In the first part of the experiment (thread pendulum), d_1 is the double length of the pendulum in mm, that is, the diameter of the circle described by the centre of gravity of the pendulum. In this case, the measured deviations of the pendulum sphere are indicated directly in rad. If measurements are carried out with the g pendulum, 12 is entered for d_1 (d_1 = d_0), because the pendulum is now coupled 1:1 with the movement measuring unit. If the values (50 ms) in the "Get value every (50) ms" dialog box are too high or too low,

Fig. 4. *Experimental set-up for the determination g from the oscillation period*

noisy or non-uniform measurements can occur. In this case adjust the measurement sampling rate appropriately. The <Start> button must then be pressed. A new measurement can be initiated any time with the <Reset> button, the number of measurement points “n” is reset to zero. In total, about n = 250 measurement values are recorded and then the <Stop> button is pressed.

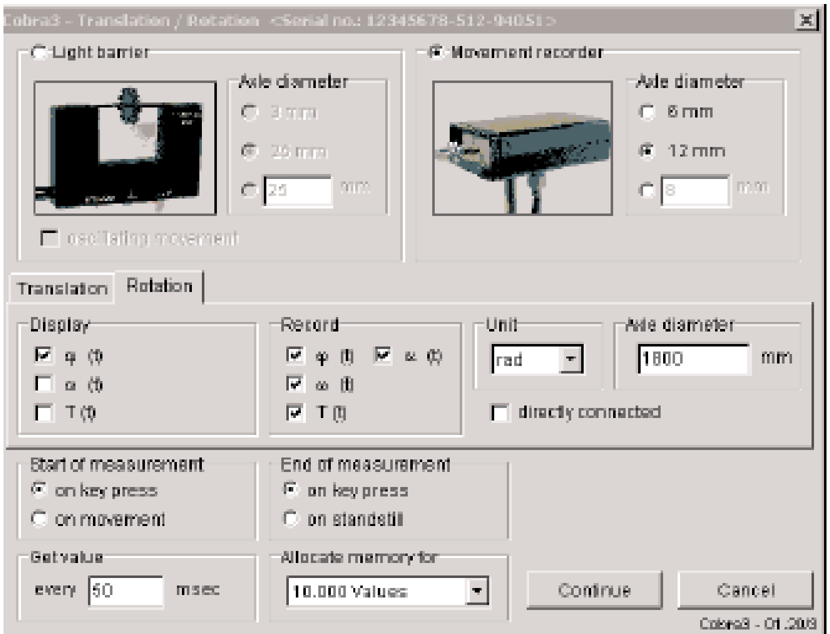


Fig.5. *Measurement parameter box*

2.2.2. Investigation for various pendulum lengths

- ***Step 1***: Choose an arbitrary pendulum length (may be 400 mm or 500 mm). Note that the pendulum length l was the distance of the centre of the supported mass from the centre of the rotational axis.
- ***Step 2***: Move the 1-g weight holder, which tenses the coupling thread between the pendulum sphere and the movement sensor, manually downward and the release it. Set the pendulum in motion (small oscillation amplitude) and click on the ”Start measurement” icon. After approximately 5 oscillations click on the ”Stop measurement” icon, a graph similar to Fig. 6 appears on the screen. Determine the duration of a period with the aid of the cursor lines, which can be freely moved and shifted onto the adjacent maxima or minima of the oscillation curve. Record the measurement result in a data sheet.

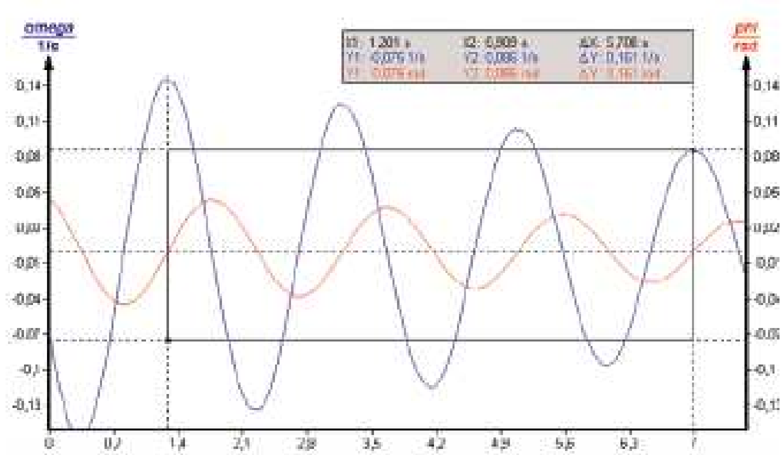


Fig. 6. *Typical pendulum oscillation*

- Step 3: Do the measurement for 5 times to get the average value of the oscillation period.

- Step 4: Repeat the measurement with different pendulum lengths (500mm and 600mm or 600mm and 700mm).

2.3. Pendulum with inclined oscillation plan

- ***Step 1***: Make the arrangement of the experimental set-up as Fig. 7. The oscillation plane is initially vertical or 0^o. Let the pendulum to vibrate with its small deflection angle. Record the duration of one period in the second data table, then repeat the measurement for more 4 times at this position.

- ***Step 2:*** Rotate the vibration plane to be inclined at 10^o and perform the measurement procedure similar Step 1.

- ***Step 3***: Repeat again the measurement with inclined plane corresponding θ = 020°, 40°, and 60°. Each angle is also 5 times of measurement.

Fig. 7. *Experimental set-up for the variable g pendulum*

III. LAB REPORT

1. Your lab report should have a data sheet with two data tables of the measurement results of as instructed in part 2.2 and 2.3.
2. Determination of the gravitational acceleration as a function of pendulum length using eq. (4) also show the uncertainty of this quantity correspond to each length.
3. Determination of the gravitational acceleration including its uncertainty as a function of the inclination of the pendulum force using eq. (5) correspond to each angle..
4. ***<u>Note</u>***: Please read the instruction of "***Significant Figures***" on page 6 of the document "***Theory of Uncertainty***" to know the way for reporting the last result.

Experiment 5

INVESTIGATION OF TORSIONAL VIBRATION

Instruments: 1. Torsion apparatus;
2. Torsion rods (steel)
3. Spring balance;
4. Stop watch;
5. Sliding weight
6. Support rods and base.

Purpose of the experiment: Bars of various materials will be exciting into torsion vibration. The relationship between the torsion and the deflection as well as the torsion period and moment of inertia will be derived. As a result, moment of inertia of a long bar can be determined.

I. THEORETICAL BACKGROUND

If a body is regarded as a continuum and if $\vec{r}_0$ and $\vec{r}$ denote the position vector of a point P in the undeformed and deformed states of the body, then for small displacement vectors:

$$\vec{u} = \vec{r} - \vec{r}_0 = (u_1, u_2, u_3) \quad (1)$$

and the deformation tensor $\vec{\varepsilon}$ is: $\varepsilon_{ik} = \dfrac{\partial u_i}{dx_k} - \dfrac{\partial u_k}{dx_i}$

The forces $d\vec{F}$ which act on a volume element of the body, the edges of the element being cut parallel to the coordinate planes, are described by the stress tensor $\vec{\sigma}$:

$$\vec{\sigma} = \frac{d\vec{F}}{dA} \quad (2)$$

Hooke's law provides the relationship between $\vec{\varepsilon}$ and $\vec{\sigma}$: $\sigma = E.\varepsilon$, where E is elastic modulus.

For a bar subjected to a torque as shown in Fig.1, the angular restoring torque or torsion modulus D_τ can be determined by:

$$\tau_z = D_\tau.\varphi \quad (3)$$

From Newton's basic equation for rotary motion, we have:

$$\tau = \frac{dL}{dt} = \frac{d}{dt}(I_z\omega) \quad (4)$$

Combination eq. 3 and 4 we obtain the equation of vibration as follows:

$$\frac{d^2\varphi}{dt^2} + \frac{D_\tau}{I_z}\varphi = 0 \quad (5)$$

The period of this vibration is:

$$T = 2\pi\sqrt{\frac{I_Z}{D_\tau}} \quad (6)$$

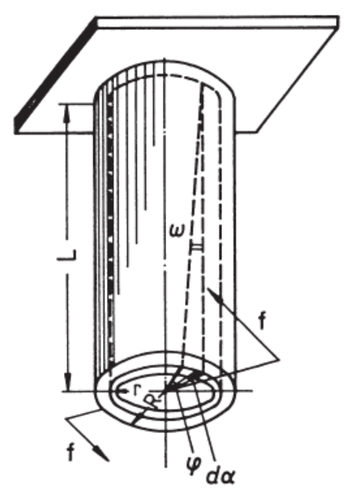


***Fig.1**: Torsion in a metal rod*

The linear relationship between τ_z and φ shown in Fig. 2 allows determining D_τ and consequently the moment of inertia of the long rod.

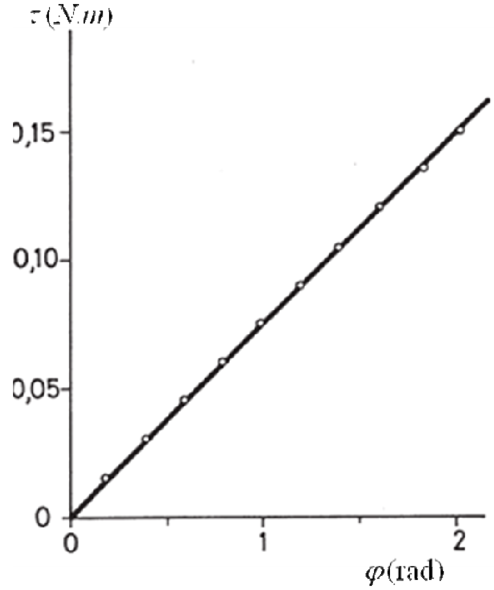


***Fig.2**: Torque and deflection of a torsion metal rod*

II. EXPERIMENTAL PROCEDURE

1. Set-up experiment

The experimental set-up is arranged as shown in Fig. 3.

- For the static determination of the torsion modulus, the Newton spring balance acts on the beam at a position which is corresponding to the lever arm *r*. to form a right angle.
- It is recommended that a long aluminum rod, 0.5 m long, 0.002 m in diameter, should be used for this experiment. The steel beam is also preferable for determining the moment of inertia of the rod with the two masses arranged symmetrically.

***Fig.3**: Experimental set-up*

2. How to perform the experiment

2.1 Determination of torque ($\tau = Fr$)

- ***Step 1***: Assemble the steel rod on the torsion apparatus.
- ***Step 2***: Put the Newton spring balance at a position on the beam that corresponds to the lever arm *r* (maybe either 100 *mm* or 150 *mm*).
- ***Step 3***: Pull the spring balance so that it is perpendicular to the beam to turn the disk being deflected an angle φ (10^o, 20^o, 30^o respectively) then record the value of force ***F*** shown on the balance's body in the first data table.
- ***Step 4***: Do the measurement corresponding to each angle for 5 times.

2.2 Determination of period time (*T*)

- ***Step 1:*** Pull out to turn the disk being deflected at angle φ (you'd better to choose the same angles as part 2.1 that is also 10^o, 20^o, 30^o).

- ***Step 2***: Let the aluminum rod being twisted that make the hand attached to the center of disk, vibration and use the stopwatch to count the duration of several vibrations.
- ***Step 3***: Record the duration of 3 periods (or 5 ones) in the second data table. At each angle, repeat the measurement for 5 times. After that, determine the time of one oscillation period (***T***) for all cases.

III. LAB REPORT

You lab report should have the following main content:

1. A data sheet having two data tables for two measurements.
2. Make a graph showing the relationship of torsion on deflection angle ϕ (in radians). You'd better to use the computer's graphing software like the excel of Microsoft office.
3. Determination of the torsion modulus D_τ. as the slope (***m***) of the graph. The slope can be either determined using the calculation $m = \frac{\Delta\tau}{\Delta\varphi}$ or the fitting tool of the computer's graphing software like the excel of Microsoft office.

<u>Note:</u> please read carefully the part "***Graph and Uncertainty***" on page 9 of the document "***Theory of Uncertainty***" to determine the uncertainty of the torsion modulus.

4. Calculation of the moment of inertia of the long rod using the eq. (6) and its uncertainty.

Experiment 6

DETERMINATION OF SOUND WAVELENGTH AND VELOCITY USING STANDING WAVE PHENOMENON

Figure 1*. Equipment for measuring standing wave*

Equipment

1. Glass tube for creating sound resonance;
2. Piston;
3. Electromotive speaker for transmitting the sound wave and microphone for detecting the resonant signal.
4. Function generator
5. Metal support and base-box;
6. The current amplifier with ampere-meter, MIKE

Purpose

To understand the physical phenomenon of standing wave and to determine the sound wavelength and propagation velocity.

I. BACKGROUND

A **standing wave**, also known as a *stationary wave*, is a wave that remains in a constant position. This phenomenon can arise in a stationary medium as a result of interference between two waves traveling in opposite directions. The effect is a series of nodes (zero displacement) and anti-nodes (maximum displacement) at fixed points along the transmission line as shown in figure 2. Such a standing wave may be formed when a wave is transmitted into one end of a transmission line and is reflected from the other end.

In this experiment, the standing wave will be investigated by equipment shown in figure 1. Here, the sound wave is generated by the frequency generator using an electromotive speaker. It travels along a glass tube and is reflected at the surface of a piston which can move inside the tube. These two waves with the same frequency, wavelength and amplitude traveling in opposite directions will interfere and produce **standing wave or stationary wave**.

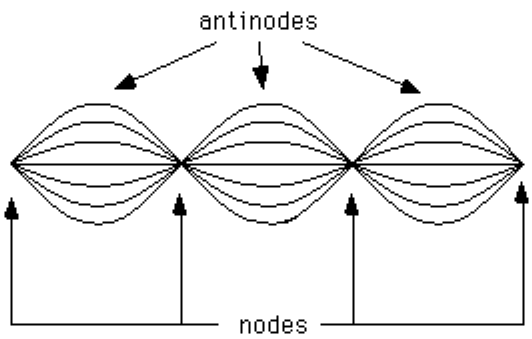


Figure 2. *Illustration of standing wave*

Considering a suitable initial moment t so that the incoming wave with frequency f making an oscillation at point **N** in form:

$$x_{1N} = a_0 .\ sin2\pi ft \tag{1}$$

where a_0 is the amplitude of the wave,

Because of **N** doesn't move ($x_N = 0$), then the reflective wave also creates an oscillation of which phase is opposite at **N**:

$$x_{2N} = -a_0 .\ \sin 2\pi f t \tag{2}$$

It means that the algebraic sum of two oscillations is equal to 0 at N:

$$x_N = x_{1N} + x_{2N} = 0 \tag{3}$$

On the other hand, considering a point M which is separated from N with a distance of:
$y = MN$

Let the velocity of the sound wave traveling in the air is v, then the phase of incoming wave at M will be earlier than that at N. In this case, the phase difference is denoted as:
$\Delta t = y/v$

The oscillation made by the incoming wave at M at moment t is the same as at N at moment t + y/v.

Then, we have:

$$x_{1M} = a_0 .\ \sin 2\pi f(t - y/v) \tag{4}$$

In opposite, the oscillation made by the reflected wave at M will be later than that at N with an amount of y/v:

$$X_{2M} = -a_0 .\ \sin 2\pi f(t + y/v) \tag{5}$$

Using a trigonometric identity to simplify, the resultant wave equation will be:

$$x_M = x_{1M} + x_{2M} = 2a_0 sin2\pi f\ (y/v)\ .\ cos2\pi ft \tag{6}$$

The sound wavelength λ (in meters) is related with the frequency f as the follows:

$$\lambda = v/f \tag{7}$$

The amplitude of the resultant wave at M is

$$a = \left| 2a_0 sin\ 2\pi(y/\lambda) \right| \tag{8}$$

Hence:

- The positions of nodes where the amplitude equals to zero are corresponding to
$$2\pi(y/\lambda) = k\pi \quad \text{or} \quad y = k.(\lambda/2) \tag{9}$$
where $k = 0,1,2,3,\dots$
- The positions of antinodes where the amplitude is maximum are corresponding to
$$2\pi(y/\lambda) = (2k+1).\pi/2 \quad \text{or} \quad y = (2k+1).(\lambda/4) \tag{10}$$
where $k = 0,1,2,3,\dots$

It can be seen from eq. (9) and (10) that the distance between two conjugative nodes or antinodes is $\boldsymbol{\lambda/2}$, that is:

$$\boldsymbol{d = y_{k+1} - y_k = \lambda/2} \tag{11}$$

Therefore, if the water column in the glass tube is adjusted so that the distance $\boldsymbol{L}$ between its open-end and point N is determined as:

$$\boldsymbol{L = k \,.\, (\lambda/2) + (\lambda/4)} \quad \text{where } \boldsymbol{k} = 0,1,2,3,\ldots \tag{12}$$

Then, there will be a nude at N and anti-nude at its open-end where the sound volume is greatest. Equation (12) is a condition to have a phenomenon of sound resonance or standing wave.

In this case, the sound resonance is detected by a microphone. The signal is shown by the ampere-meter of current amplifier. Then, the phenomenon can be recorded by observing the maximum deviation of ampere-meter's hand corresponding to due to the position of piston. By measuring the distance between two conjugative nodes or antinodes the sound wavelength λ (in meters) and velocity of the sound wave can be determined using eqs. (11) and (7).

II. EXPERIMENTAL PROCEDURE

- ***Step 1***: Switch the frequency knob on the surface of base-box to the position of 500 Hz
- ***Step 2***: Turn slowly the crank to move up the piston and simultaneously observe the movement of ampere-meter's hand until it gets the maximum deviation.
- ***Step 3***: Record the position $\boldsymbol{L_1}$ of the piston corresponding to the maximum deviation of ampere-meter's hand in table 1 of the report sheet.

  <u>Note</u>: The position $\boldsymbol{L_1}$ is determined corresponding to the marked line on the piston.
- ***Step 4***: Continue to move up the piston and observe the movement of microampere-meter's hand until it gets maximum position of the deviation once again.
- ***Step 5***: Again, record the second position of the piston $\boldsymbol{L_2}$ (in millimeters) in table 1.
- ***Step 6***: Repeat the experimental steps of 2 to 5 for more 4 times.
- ***Step 7***: Perform again all the measurement procedures (from step 1 to step 6) corresponding to the frequencies of 600 Hz and 700 Hz. The measurement results are recorded in table 2 and 3, respectively.

III. LAB REPORT

Your lab report should include:

1. The data sheet having 3 data tables corresponding to frequencies of 500 Hz, 600 Hz, and 700 Hz.
2. Calculate the wavelength and speed of sound as well as their uncertainties for each frequency.
3. Theoretically, the speed of sound at a temperature T can be calculated as follows:

$$v = v_0 \cdot \sqrt{1+\alpha.T}$$

where v_0 = 332 m/s is the speed of sound at temperature of 0 ^{0}C, and α = 1/ 273 degree^{-1}
Calculate this speed (note that the value of room temperature depends on the measurement time) then compare it to those obtained by experiment.

4. ***<u>Note</u>***: Please read the instruction of "***Significant Figures***" on page 6 of the document "***Theory of Uncertainty***" to know the way for reporting the last result.