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GENERAL PHYSICS (3) LABORATORY

PHYS 203 LAB

STUDENT MANUAL

Name:-

ID#

KING ABDULAZIZ UNIVERSITY
PHYSICS DEPARTMENT
1st semester 1430H

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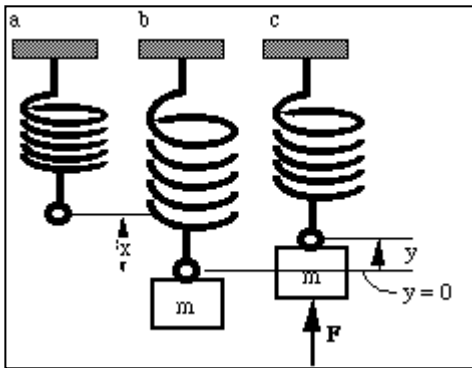
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HOOKE'S LAW AND THE SIMPLE HARMONIC OSCILLATION

OBJECTIVE:

- 1) To study the simple harmonic motion for vertically suspended spring.
- 2) To determine the spring constant using Hooke's law and then using the oscillating system and compare the two results.

THEORY:



When a mass is attached to a vertically suspended spring, the spring stretches to an equilibrium position as shown in figure 1(b). According to Hooke's law, the weight is proportional to the elongation of the spring as long as the elastic limit of the spring is not exceeded.

$$F = kx \quad (1)$$

Where F is the force acts on the spring, k is spring constant and x is the spring elongation. In our example, the force which acts on the spring is the weight of the block. Thus, we can rewrite equation (1) as

$$mg = kx \quad (2)$$

And the elongation can be expressed as

$$x = \frac{mg}{k} \quad (3)$$

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If the mass is now displaced from its equilibrium position, the same equation still applies, where x is now that displacement. In other words, when such a displacement is made, a restoring force acts to return the mass to its equilibrium position. Upon release, the mass moves toward the equilibrium position, but its inertia causes it to “overshoot” this point. The motion then continues through the equilibrium position and beyond until the friction force eventually stops the mass at the equilibrium position. The motion then repeats itself back and forth through the position of equilibrium. The period of this oscillation is given by

$$T = 2\pi \sqrt{\frac{m_{total}}{k}} \quad (4)$$

where the total mass, m_{total} , equals the sum of the attached mass to the spring, m , and the effective mass of the spring, m_{eff} , thus

$$m_{total} = m + m_{eff} \quad (5)$$

using equation 5, one can rewrite equation 4 as

$$T^2 = \frac{4\pi^2}{k} m + \frac{4\pi^2}{k} m_{eff} \quad (6)$$

The effective mass of the spring is found theoretically to be one-third the mass of the spring, M , i.e.

$$m_{eff} = \frac{M}{3} \quad (7)$$

PROCEDURE:

a) Hooke's law:

- 1- Adjust the apparatus to make the upper indicator points to the end of the spring and record the reading on the scale.
- 2- Add 0.05 kg mass to the spring and place the lower indicator at the end of the spring and record the reading. Calculate the displacement by taking the difference between the two readings.
- 3- Repeat step 2 with 0.10, 0.15 and 0.20 kg masses and tabulate the results.
- 4- Plot the displacement x versus the mass m . Use the graph to calculate the spring constant k .

b) Simple harmonic oscillation:

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- 1- Place the same loads used in (a). Displace the spring vertically a *small* distance and then release it (*be careful to avoid any sidewise motion*).
- 2- With a stopwatch observe the time for 20 complete oscillations. Find the period T by dividing the recorded time by the number of whole oscillations made during that interval.
- 3- Plot the square of the period T^2 versus added mass m. Use the graph to find k and compare it with the value obtained from Hooke's law.
- 4- Use the intercept to find the spring effective mass and compare the observed value with the theoretical value.

MEASUREMENTS AND RESULTS:

M=

Upper Indicator reading =

m (kg)	Lower Indicator reading (m)	x (m)	Time for 20 oscillations				T (s)	$T^2 (s^2)$
			t ₁ (s)	t ₂ (s)	t ₃ (s)	t _{avg} (s)		

Using graphs calculate the following:

a) Hooke's law:

$$k = \frac{g}{\text{slope}}$$

b) Simple harmonic oscillation:

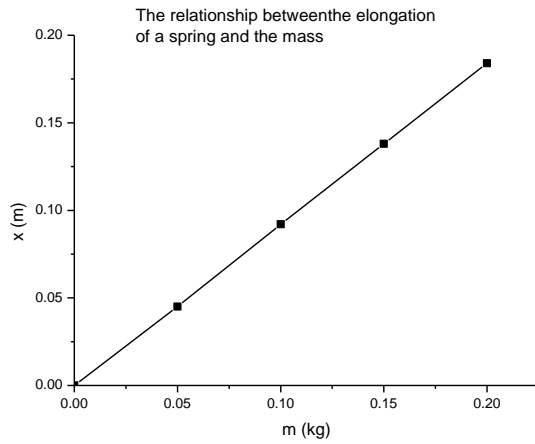
$$k = \frac{4\pi^2}{\text{slope}}$$

$$m_{eff} = \frac{k \times \text{intercept}}{4\pi^2}$$

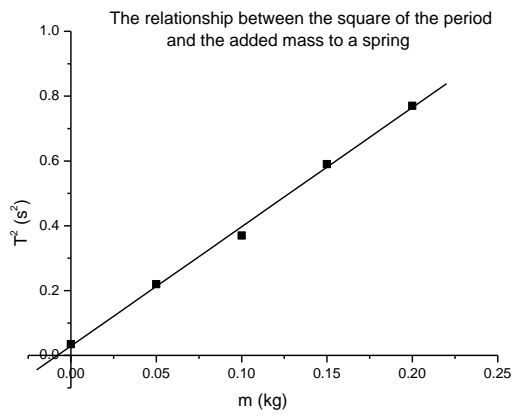
$$m_{eff} = \frac{M}{3}$$

GRAPHS:

a) Hooke's law:



b) Simple harmonic oscillation:



COMPOUND (PHYSICAL) PENDULUM

OBJECTIVE:

Use the compound pendulum to find:

- 1) The acceleration due to gravity g .
- 2) The moment of inertia of the rod.

THEORY:

Any object mounted on a horizontal axis so as to oscillate under the force of gravity is a compound pendulum. The one used in this experiment is a uniform rod suspended at different locations along its length. The period T of a compound pendulum is given by

$$T = 2\pi \sqrt{\frac{I}{Mgh}} \quad (1)$$

Where:

I is the rotational inertia of the pendulum about the axis of suspension

M is the pendulum mass

And h is the distance between the suspension point and the center of mass.

Using the parallel axis theorem

$$I = I_G + Mh^2 \quad (2)$$

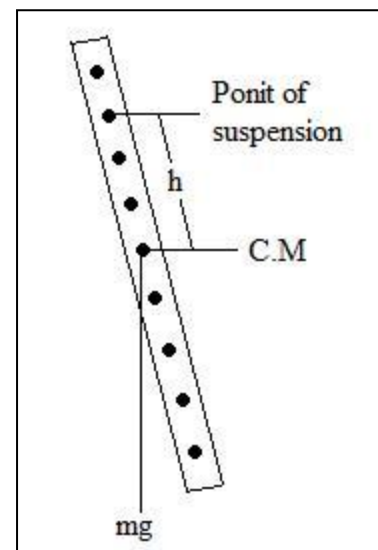
I_G is the rotational inertia of the body about its center of mass and it is given by

$$I_G = MK^2 \quad (3)$$

Substituting equation 3 in equation 2

$$I = M(h^2 + K^2) \quad (4)$$

Where K is the radius of gyration .substituting equation 4 in equation 1



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$$T = 2\pi\sqrt{\frac{h^2 + K^2}{gh}} \quad (5)$$

The period of the simple pendulum is given by

$$T = 2\pi\sqrt{\frac{L}{g}} \quad (6)$$

The period of a compound pendulum equals the period of a simple pendulum of a length

$$L = \frac{h^2 + K^2}{h} \quad (7)$$

This equation can be solved to find L and K:

$$L = h_1 + h_2 \quad (8)$$

$$K = \sqrt{h_1 h_2} \quad (9)$$

PROCEDURE:

- 1- First hang the pendulum horizontally and move it until it reaches equilibrium so you can find the center of mass and mark it.
- 2- Secondly hang it vertically inserting the tip of the knife in the first hole from the center of mass. Then set it oscillating through a small angle.
- 3- Measure the time needed for 20 oscillations and the corresponding h.
- 4- Repeat steps 2 and 3 for the other holes.
- 5- Record your measurements in a table.

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MEASUREMENTS AND RESULTS:

M=

One Side from C.M			The other side of C.M		
h(m)	20T (s)	T(s)	h(m)	20T (s)	T(s)

From the graph:

T	h ₁ (average)	h ₂ (average)	L=h ₁ +h ₂	K= $\sqrt{h_1 h_2}$	$g = \frac{4\pi^2 L}{T^2}$	I _G =MK ²
(s)	(m)	(m)	(m)	(m)	(m/s ²)	Kg m ²

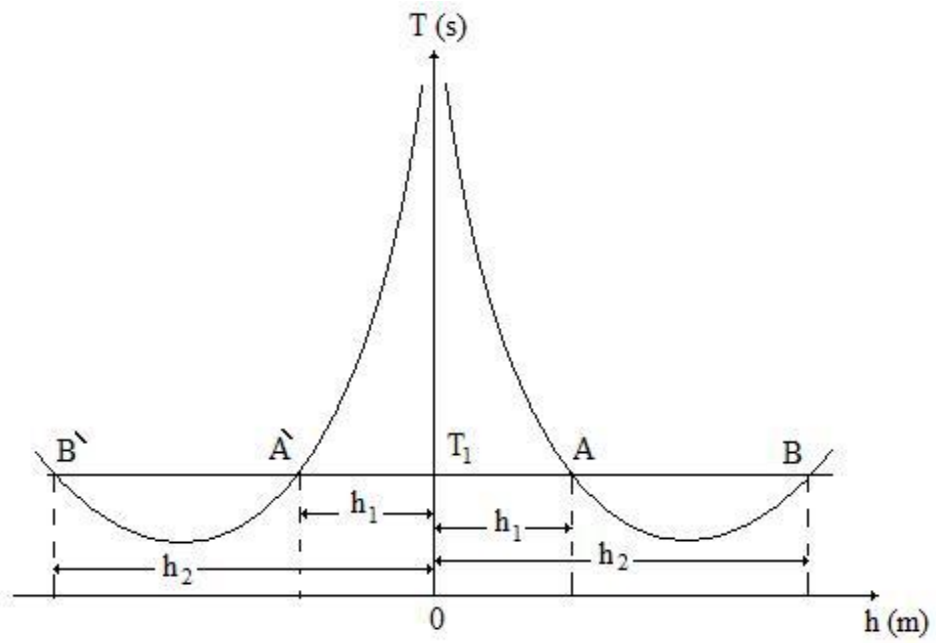
Finally calculate:

g (average)

I_G (average)

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GRAPHS:



STANDING WAVES IN VIBRATING STRING

OBJECTIVE:

- 1) To investigate the properties of standing waves in string by means of Melde's experiment.
- 2) To determine the frequency of vibration in string.

THEORY:

When standing waves are formed on a string, the length of the string, L , and the wavelength of the oscillation, λ , are related according to the following equation

$$L = \frac{n\lambda}{2} \quad (1)$$

Or

$$\lambda = \frac{2L}{n} \quad (2)$$

Where n is the number of the antinodes or the harmonic number.

The speed of a wave in the string is given by

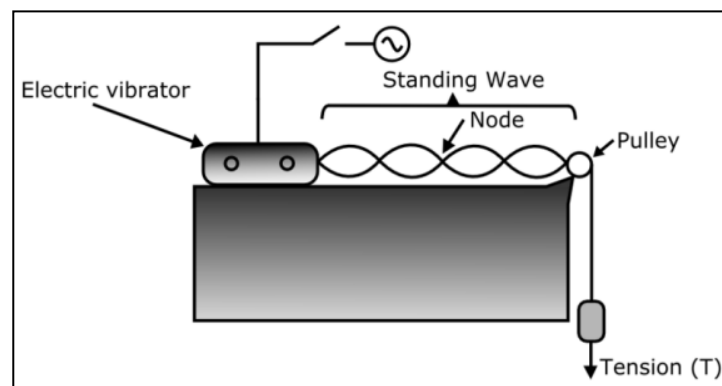
$$v = \sqrt{\frac{\tau}{\mu}} \quad (3)$$

Where τ is the tension on the string and μ is its linear density.

Using the general relation $v=f\lambda$ along with equation 2 and 3, the harmonic number can be expressed as

$$n^2 = \frac{1}{\tau} (4 f^2 L^2 \mu) \quad (4)$$

Thus by changing the tension on the string, the number of antinodes can be changed and from their relation the frequency of vibration can be calculated.



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PROCEDURE:

- 1- Take a segment of the string and measure its length and, S, and mass, m. Calculate the linear density of the string, μ .
- 2- Measure the length of the string between the vibrator and the pulley, L.
- 3- With the vibrator operating switch turned on, adjust the tension in the string so that the string is set up to the first harmonic. Record the dynamometer reading.
- 4- Keep the length of the string constant and repeat step 2 to find the tension required to set up the string to the second harmonic, third harmonic, fourth harmonic and fifth harmonic. Tabulate your results.
- 5- Plot the square of the harmonic number against the reciprocal of the tension. Find the slope and then calculate the frequency.

MEASUREMENTS AND RESULTS:

$$S =$$

$$m =$$

$$L =$$

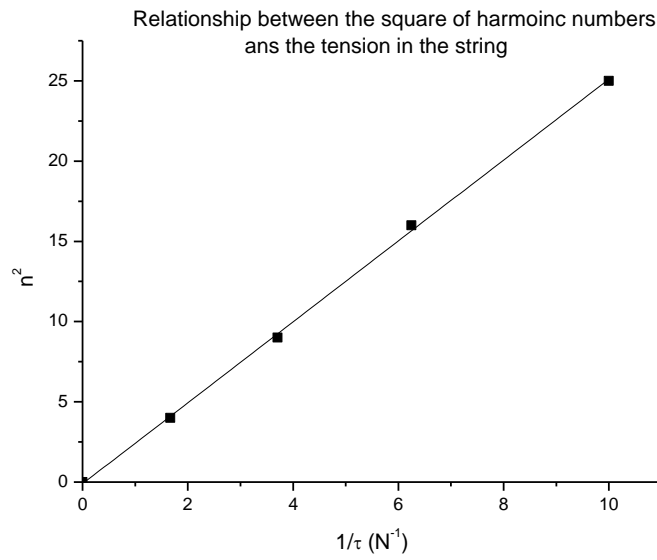
τ (N)	$\frac{1}{\tau}$ (N^{-1})	n^2

$$\mu = \frac{m}{S}$$

$$f = \frac{1}{2L} \sqrt{\frac{\text{slope}}{\mu}}$$

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GRAPHS:



VELOCITY OF SOUND

OBJECTIVE:

- 1) To illustrate resonance in a pipe closed at one end.
- 2) To determine the velocity of sound.

THEORY:

Waves propagated down the tube are reflected at the closed end and stationary vibrations are produced by the interference of the incident and reflected wave trains. The air is at rest at the closed end, which is therefore a node, and for resonance the open end must be an antinode. Actually the antinodes are situated a short distance X (known as the end correction) beyond the open end of the tube. Figure 1 indicates the conditions of vibration for the first two positions of resonance, from which we have

$$L_1 + x = \lambda / 4 \quad (1)$$

The speed of the wave equals the product of its frequency and its wavelength, i.e.

$$v = f\lambda \quad (2)$$

By substituting equation 2 in 1 we have the following relation

$$L_1 + x = \left(\frac{1}{4}\right) \frac{v}{f} \quad (3)$$

Or

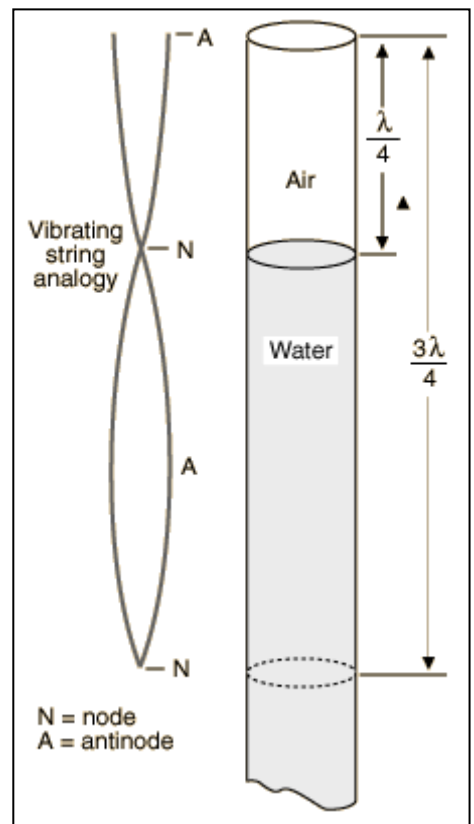
$$L_1 = \left(\frac{v}{4}\right) \frac{1}{f} - x$$

The end correction is found to be related to the tube radius by

$$X = 0.6 R$$

Where:

L_1 = the length of the air column for the first resonance



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v :is the velocity of sound at room temperature.

f :the frequency of the tuning fork.

X :is the end correction

R :is the radius of the tube.

By comparing to linear graph equation and plotting L_1 against $1/f$:

$$v = 4 \text{ slope} \quad (4)$$

PROCEDURE:

- 1- Strike one of the tuning forks with the rubber mallet supplied and hold it above the water column. Do not touch the tube with the tuning fork.
- 2- Lower the water surface slowly, listening for amplification of the tone. When a resonance is found, a pronounced reinforcement of the sound will be heard. Move the water surface up and down several times to locate the point of maximum sound intensity and record the reading of L_1 .
- 3- Repeat steps 1 and 2 for the other forks.

MEASUREMENTS AND RESULTS:

R=

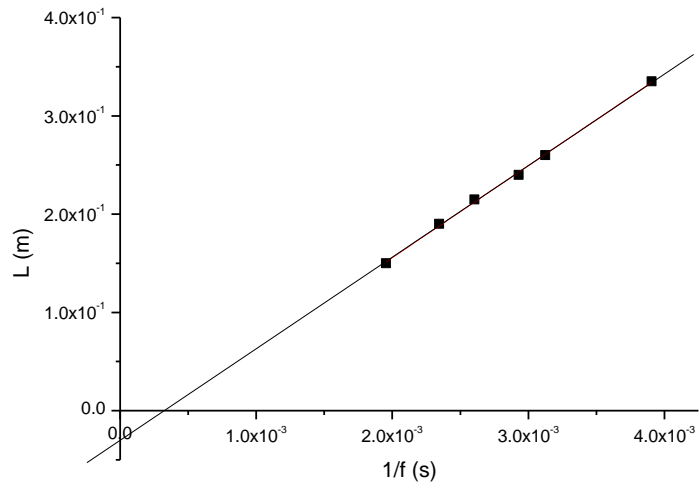
f(Hz)	$\frac{1}{f}$ (s) $\times 10^{-3}$	L_1 (m) $\times 10^{-2}$

Slope=

$$V=4(\text{slope})$$

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GRAPHS:



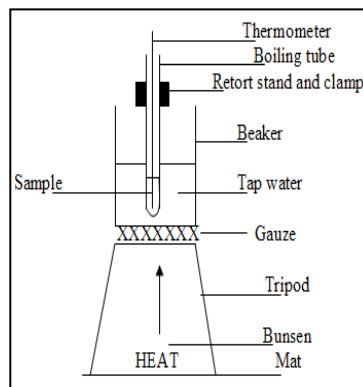
MELTING POINT AND COOLING CURVE OF A SOLID MATERIAL

OBJECTIVE:

- 1) To draw the cooling curve of a solid material.
- 2) To determine the melting point of wax.

THEORY:

A cooling curve is actually a line graph representing the change in the state of matter of a substance, either from solid to liquid or liquid to solid. In this graph, time is usually represented on the x - axis and temperature on the y - axis. The particles in the wax in the solid state slowly start to get more energy when heated and start to move more rapidly at a certain temperature and then change to liquid. When it has to change from liquid to solid, the particles in the wax start to lose energy and come close together till they become solid. In this experiment the temperature is expected to drop dramatically at first as the liquid cools, then to remain constant for a while when the substance reaches its melting point, and then to drop slowly as the thermometer cools to room temperature



PROCEDURE:

- 1- Melt the wax in a warm water bath.
- 2- When the wax is melted entirely, remove it from the bath, dry it and then bury it in sand. Record the temperature each 30 seconds while the liquid is converting to solid. At the same time watch for constant temperature at which there was both liquid and solid present.

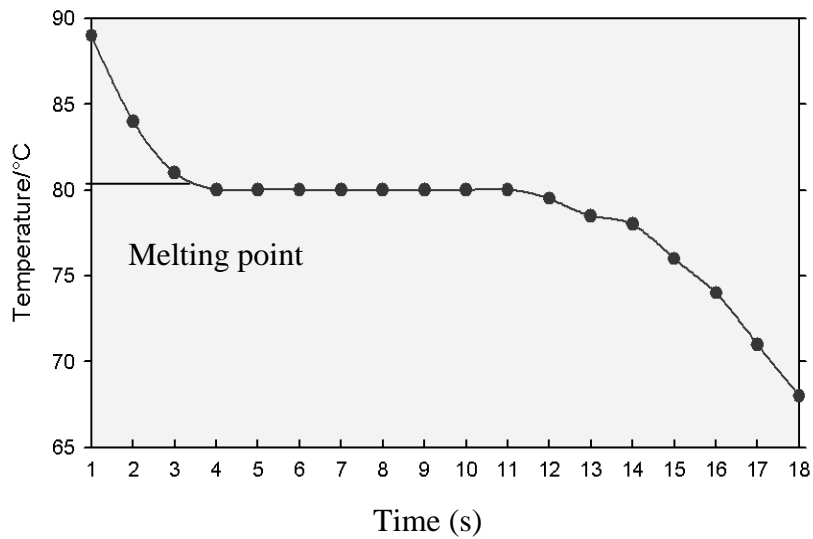
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MEASUREMENTS AND RESULTS:

Time(s)	T(°C)

Melting point of wax =

GRAPHS:



LINEAR EXPANSION COEFFICIENT

OBJECTIVE:

To measure the coefficient of linear expansion for a metal rod.

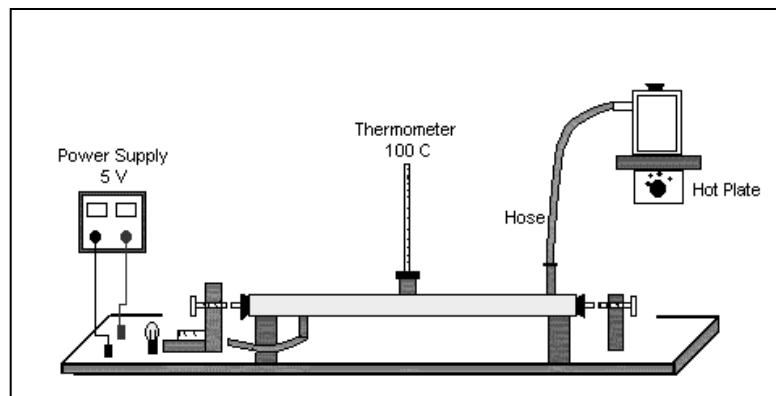
THEORY:

Most materials expand when heated through a temperature range that does not produce a change of phase. The added heat increases the vibrational kinetic energy of the atoms in the material, which in turn increases the distance between the atoms. In an isotropic material, the expansion occurs equally in all dimensions.

If an object of length L is heated through a *small* temperature change ΔT , the change in length ΔL is proportional to the original length and to the change in temperature, i.e.

$$\Delta L = \alpha L \Delta T \quad (1)$$

The proportionality constant α is known as the coefficient of linear expansion.



PROCEDURE

- 1- Measure the length of the rod and record as L .
- 2- Insert the rod in the steam jacket. Adjust the screw at the fixed end so that good contact is made. Carefully insert the thermometer through the stopper until it barely touches the rod. Record the temperature as T_1 .
- 3- Run tap water through the jacket. The water should enter through the lower opening. Allow the temperature to reach a constant reading, i.e. it should not vary by more than 0.2°C in one minute.
- 4- Adjust the micrometer screw until it just barely touches the rod. **DO NOT FORCE THE MICROMETER SCREW.** Record the scale reading and the dial reading.

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5- Back the micrometer screw off by about 2.00 mm and admit steam to the jacket. Let the condensed steam run into the sink. After the temperature has remained steady for 3 or 4 minutes, read the thermometer and record as T_2 .

6- Adjust the micrometer screw until it just touches the rod. Record the scale and dial readings.

MEASUREMENTS AND RESULTS:

L=

T_1 =

Micrometer reading before heating:

T_2 =

Micrometer reading after heating:

$\Delta L = \text{Micrometer reading after heating} - \text{Micrometer reading before heating}$

$$\Delta T = T_2 - T_1$$

$$\alpha = \frac{\Delta L}{L\Delta T}$$

SPECIFIC HEAT CAPACITY OF WATER

OBJECTIVE:

To measure the specific heat capacity of water using electric method.

THEORY:

When charges move through a resistor, an electrical energy transferred into heat. The rate at which such transformations occurs is given by,

$$\frac{E}{t} = IV \quad (1)$$

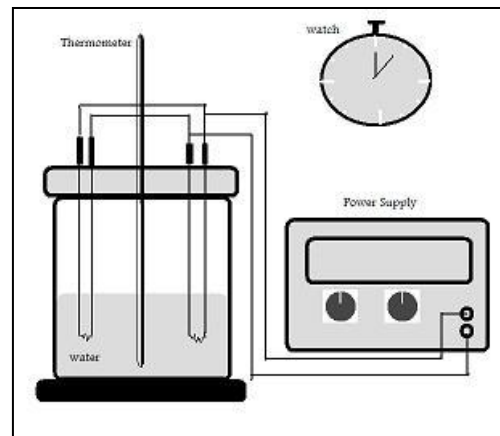
Where E is the electrical energy, I is the current through the resistor, V is the voltage across it and t is the time interval during which the energy is transferred.

If this energy is used to heat a certain mass of water, m , the heat which is absorbed by water is given by,

$$Q = cm\Delta T \quad (2)$$

Where the c is the specific heat of water and ΔT is the temperature difference for water before and after heating. If the water and the resistor are isolated then

$$Q = E \quad (3)$$



To determine the specific heat of water, we are using arrangement such as that given in figure 1. In this case, the heat generated in the resistors is transferred to both the calorimeter and the water, so the total heat is given by

$$Q = (cm + q)\Delta T \quad (4)$$

Where q is the amount of heat per Kelvin that calorimeter absorbs.

Using equations (1) and (4), equation (3) can be rewritten as

$$IVt = (cm + q)\Delta T \quad (5)$$

Solving for c , yields

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$$c = \frac{1}{m} \left(\frac{IVt}{\Delta T} - q \right) \quad (6)$$

PROCEDURE:

- 1- Find the mass of the calorimeter while it is empty. Fill the calorimeter with 200 ml of water and find its mass again. Calculate the mass of the water.
- 2- Connect the circuit as shown in figure 1.
- 3- Adjust the power supply so current of 3A pass through the resistors. Record the voltmeter reading.
- 4- Record the initial temperature T_i and at the same time turn on the stopwatch.
- 5- Stir continuously and let the temperature to rise about 10C° above the initial value. Record the elapsed time, t , and the final temperature T_f
- 6- Calculate the specific heat of water using equation 6. Calculate the error percentage between your result and the known value of $4186 \text{ J Kg}^{-1} \text{ K}^{-1}$

MEASUREMENTS AND RESULTS:

Mass of Calorimeter and Water	$M =$	
Mass of Calorimeter	$m_c =$	
Mass of Water	$m =$	
Heat Capacity of Calorimeter	$q =$	100 J/K
Voltage Drop Across Heater Coil	$V =$	
Current Flowing in Heater Coil	$I =$	
Initial Temperature	$T_i =$	
Final Temperature	$T_f =$	
Temperature Difference	$\Delta T =$	

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$$m = M - m_c$$

$$\Delta T = T_f - T_i$$

$$c = \frac{1}{m} \left(\frac{IVt}{\Delta T} - q \right)$$

% error =

$$c = 4186 \text{ J Kg}^{-1} \text{ K}^{-1}$$

THERMAL CONDUCTIVITY OF RUBBER

OBJECTIVE:

To find the thermal conductivity coefficient of rubber.

THEORY:

In this experiment, a cylindrical rubber tube is immersed in a calorimeter filled with water. Steam is allowed to pass through the tube. The heat transfer across the wall of the tube is given by the formula:

$$Q = \frac{k2\pi Lt(\theta_1 - \theta_2)}{\ln\left(\frac{r_o}{r_i}\right)} \quad (1)$$

where:

L = length of the tube (m)

r_i = inner radius of the tube (m)

r_o = outer radius of the tube (m)

Q = is the heat transfer (J)

k = thermal conductivity coefficient ($\text{W m}^{-1} \text{K}^{-1}$)

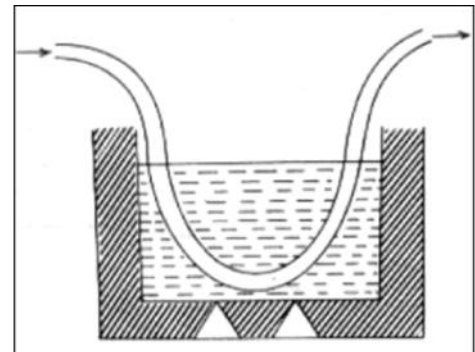
t = is the time (s).

The heat gained by the water is given by:

$$Q = (m_{cal}c_{cal} + m_w c_w)(\theta_4 - \theta_3) \quad (2)$$

The heat gained by water equals the heat lost by the calorimeter i.e, by equating equations 1 and 2:

$$k = \frac{(m_{cal}c_{cal} + m_w c_w)(\theta_4 - \theta_3) \ln\left(\frac{r_o}{r_i}\right)}{2\pi Lt(\theta_1 - \theta_2)}$$



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PROCEDURE:

- 1- Find the mass of the calorimeter then fill it with a suitable amount of water and find its mass again.
- 2- Immerse a suitable length of the tube inside the water and mark it.
- 3- Allow the steam to pass through the tube until the temperature of the water rises approximately 10 degrees.
- 3- Record the initial and final temperatures of water and the calorimeter and also the time taken for this change of temperature.
- 4- Measure the marked length of the tube, the inner radius and, and outer radius.
- 5- Calculate k .

MEASUREMENTS AND RESULTS:

$$m_{cal} = \dots\dots\dots$$

$$m_1(\text{calorimeter+water}) = \dots\dots\dots$$

$$m_w = (m_1 - m_{cal}) =$$

$$\theta_3(\text{initial temperature of water and calorimeter}) = \dots\dots\dots$$

$$\theta_4(\text{final temperature of water and calorimeter}) = \dots\dots\dots$$

$$t = \dots\dots\dots$$

$$L = \dots\dots\dots$$

$$r_i = \dots\dots\dots$$

$$r_o = \dots\dots\dots$$

$$\theta_1(\text{temperature of inner surface of tube (temperature of steam)}) =$$

$$\theta_2(\text{temperature of outer surface of tube}) = \frac{\theta_3 + \theta_4}{2}$$

Calculate k of rubber using the following formula:

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$$k = \frac{(m_{cal}c_{cal} + m_w c_w)(\theta_4 - \theta_3) \ln\left(\frac{r_0}{r_i}\right)}{2\pi L t(\theta_1 - \theta_2)}$$

$$k = \dots\dots\dots \text{W m}^{-1} \text{K}^{-1}$$

Given that:

$$c_w = 4186 \text{ J Kg}^{-1} \text{ K}^{-1}$$

$$c_{cal} = c_{copper} = 385 \text{ J Kg}^{-1} \text{ K}^{-1}$$

VISCOSITY MEASUREMENTS USING FALLING BALL VISCOMETER

OBJECTIVE:

- 1) To determine the coefficient of viscosity for liquid.
- 2) To study the relationship between the falling object's movement and the liquid viscosity.

THEORY:

When a ball falls in a quiescent viscous fluid, it initially accelerates under its gravity force. However, at some point the drag force and the buoyancy force will balance the gravity force which results in an equilibrium state, and the ball will move with a constant velocity that is called the terminal velocity.

When the ball reaches the terminal velocity, it has zero acceleration, and the force balance requires:

$$F_d = mg - F_b \quad (1)$$

Where mg is the gravity force, F_b is the buoyancy force, F_d is the drag force on the ball, m is the mass of the ball and g is the gravitational acceleration.

Using the relation between mass, volume and density, along with Archimedes's principle, equation 1 can be rewritten as:

$$F_d = \frac{1}{6}(\rho_s - \rho_f) g\pi d^3 \quad (2)$$

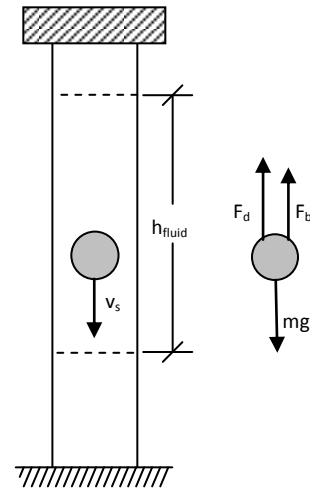
Where d is the falling ball diameter, ρ_s is the ball density and ρ_f is the fluid density. However, according to Stokes' law, the drag force can be obtained as following:

$$F_d = 3\pi\eta vd \quad (3)$$

By combining the above two equations, we have:

$$\eta = \frac{gd^2}{18v}(\rho_s - \rho_f) \quad (4)$$

This equation provides a formula for computing the fluid viscosity.



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PROCEDURE:

a) Measuring liquid density:

Record the empty beaker mass, the volume of the sample liquid and the mass of the beaker when it is filled with sample liquid. Calculate the density of the liquid.

b) Measuring balls density:

- 1- Measure the mass of the ball using electronic scale and its diameter using micrometer.
- 2- Calculate the ball volume and its material's density.
- 3- Turn the jacket tube that contains the liquid 180°. Let the ball fall and measure the time that it takes to pass between the two marks at the top and the bottom (10 cm).
- 4- Calculate the velocity of the ball and the viscosity of the liquid.
- 5- Repeat these steps for the two other liquids.

MEASUREMENTS AND RESULTS:

	Liquid	Mass of empty beaker (kg)	Mass of filled beaker (kg)	Mass of the sample liquid (kg)	Volume of the sample liquid (m ³)	Density of the liquid ρ_f (kg/m ³)
Liquid #1						
Liquid #2						
Liquid #3						

	t ₁ (s)	t ₂ (s)	t _{avg.} (s)
Ball #1			
Ball #2			
Ball #3			

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Quantity	Symbol (unit)	Ball #1	Ball #2	Ball #3
Mass	m (kg)			
Diameter	d (m)			
Radius	r (m)			
Volume	V (m ³)			
Density	ρ_s (kg/m ³)			
Distance	h (m)	0.10	0.10	0.10
Time	t (s)			
Velocity	v (m/s)			
Viscosity	η (Pa.s)			

$$V = \frac{4}{3}\pi r^3$$

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

$$v = \frac{h}{t}$$

$$\eta = \frac{gd^2}{18v}(\rho_s - \rho_f)$$

$$1 \text{ liter} = 10^{-3} \text{ m}^3$$

Discussion:

Q1. Rank the three liquids according to their viscosity, greater first.