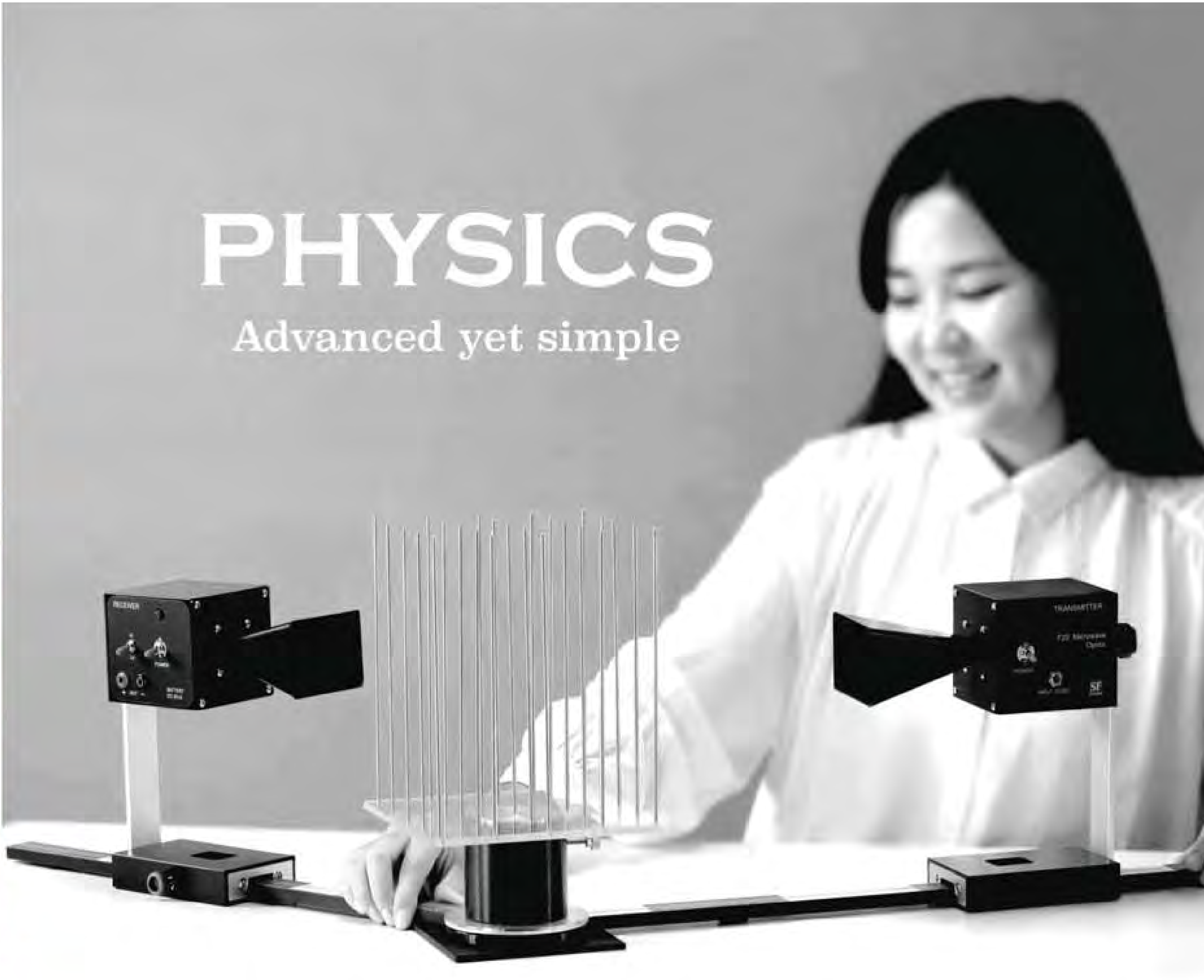
SF
SCIENTIFIC

MADE
IN
TAIWAN

- MECHANICS
- VIBRATIONS AND WAVES
- THERMODYNAMICS
- ELECTRICITY AND MAGNETISM
- LIGHT AND OPTICS
- MODERN PHYSICS

PHYSICS

Advanced yet simple

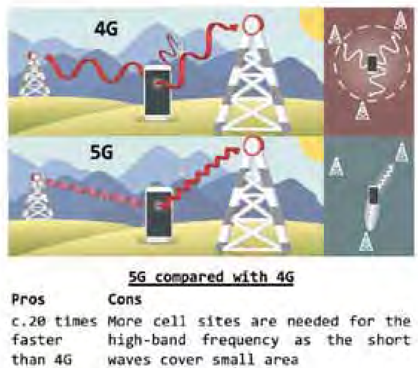


SF Scientific Co., Ltd. was first established to produce high accuracy experimental equipment for the International Physics competitions. Since then, the simple operation and reliable quality have been our aspiration. After years of continuous modification, we are now presenting our first comprehensive 28 sets of equipment. The products launched in this catalog develop the university and high school student's basic calculation and analysis skills through the quantitative experiments together with computers as auxiliary tools. Divided into six different categories, all the basic experiments necessary for learning Physics can be performed and each set equipment contains multiple experiments. Moreover, we plan to provide the teachers with inspiring and engaging demonstration instruments for innovative teaching.

CONTENTS:

THERMODYNAMICS

ELECTRICITY AND MAGNETISM



LIGHT AND OPTICS

MODERN PHYSICS

APPENDIX

More demonstrations are coming soon …

Product packaging

PP corrugated box:
Lightweight and durable. Organizing checklist attached.

EPE blocks:
separation to prevent damaging.

STATIC EQUILIBRUM IN DAILY LIFE

Experiments:

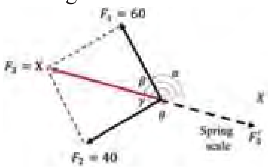
1. Force equilibrium
2. Torque equilibrium
2.1. Multi forces applied on circle
2.2. Parallel forces applied on a rod
3. Application of force equilibrium
3.1. Force on a slope
3.2. Triangle suspension torque
3.3. The mechanical advantage of the pulley

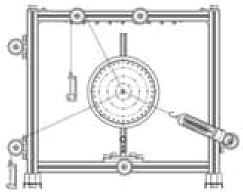
Example:

Force equilibrium:

Objects that are either at rest or moving with constant velocity are said to be in equilibrium. As $\vec{a} = 0$, Newton's second law applied to an object in equilibrium gives: $\sum \vec{F} = 0$.

A. Parallelogram method:





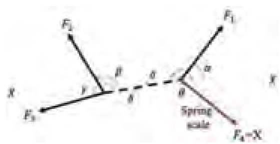
B. Triangle method: $F_3 = F_3' = \sqrt{F_1^{\,2} + F_2^{\,2} + 2F_1F_2\cos\gamma}$

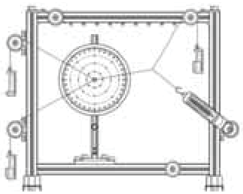
C. Analytical method: $F_3 = \frac{-F_1\cos\alpha - F_2\cos\beta}{\cos\theta}$

D. The law of Sine: $F_3 = \frac{F_1\sin(\beta-\alpha)}{\sin(\theta-\alpha)}$

Method	F_3 (g)		Error (%)
	Theoretical	*Experimental*	
Parallelogram	68	72	5.8
Triangle	70.64		1.9
Analytical	72.2		0.2
The law of Sine	67.08		7.3

Alternative configuration:

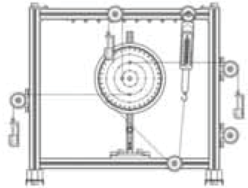


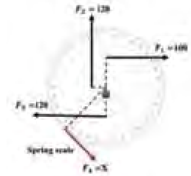


Torque equilibrium:

Total torque at the equilibrium equals to:

$$\sum\tau = (\vec{r_1} \times \vec{F_1}) + (\vec{r_2} \times \vec{F_2}) + (\vec{r_3} \times \vec{F_3}) + (\vec{r_4} \times \vec{F_4}) = 0$$

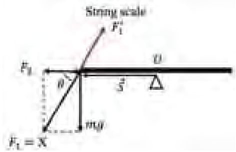


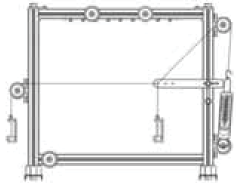


Estimated force: 140 g
Measured force: 150 g
The error: 7.1%

Triangle suspension torque:

How the weight of the object is spread between the sling and the cantilever when the crane lifts the building materials can be explained by static equilibrium.

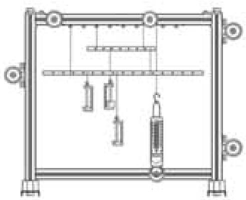




Experimental F_1	148	134	122
F_2	140	120	100
Theoretical F_1'	152	134.4	116.5
Error (%)	2.6	0.3	4.7

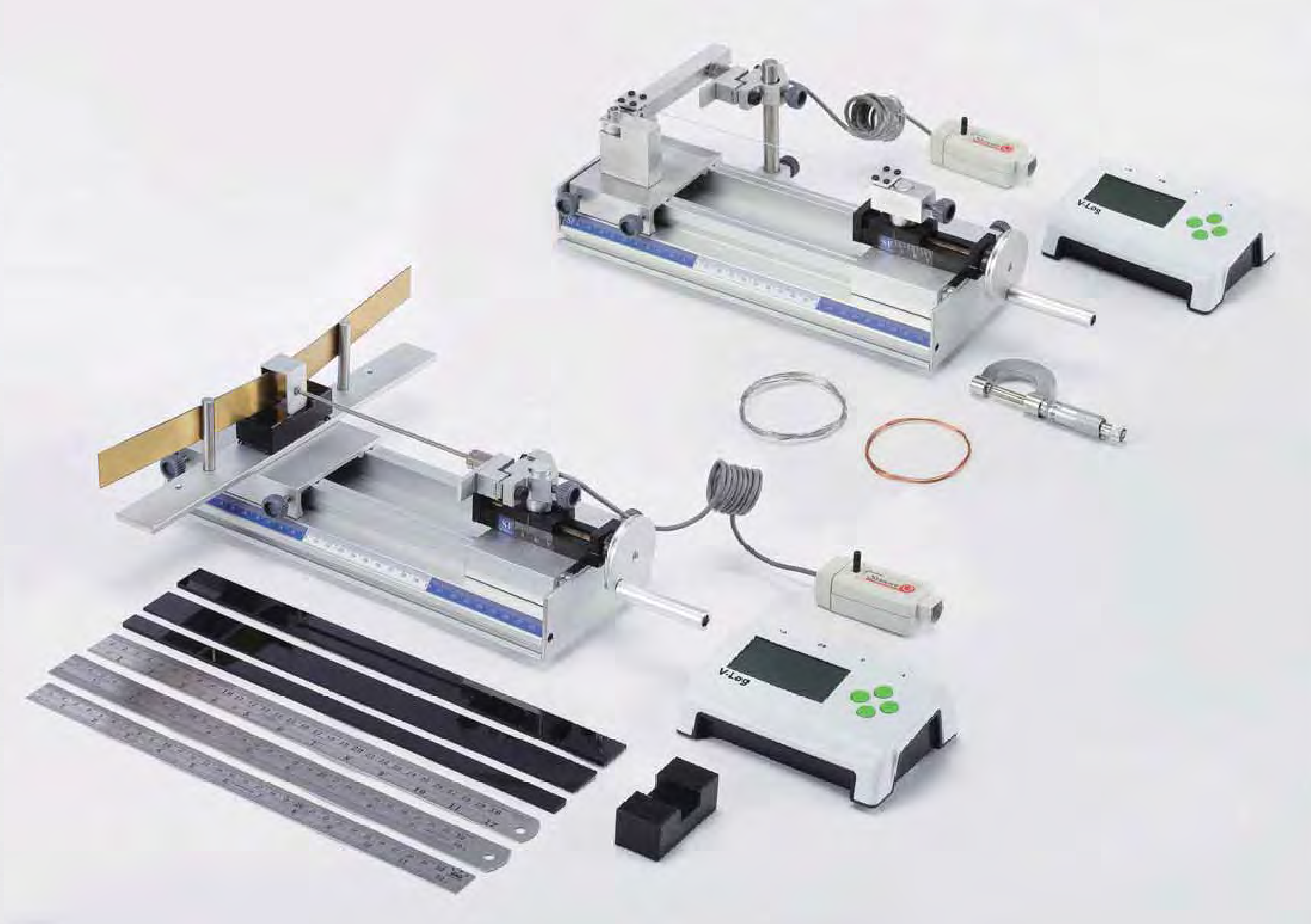
Torque balance of double lever:

The balance can be measured as:



Short rod: $F_1 = \frac{114\times12+0.1\times14\times1-80\times4-0.9\times14\times9}{16} = 58.5$

Long rod: $F_1' = \frac{40\times 8+40\times16+0.9\times28\times18-0.1\times28\times2}{24} = 58.6$


V-Log
V-Log

Experiments:

1. Determine Young's modulus by deflection of a beam
2. Stress-strain curve of a wire

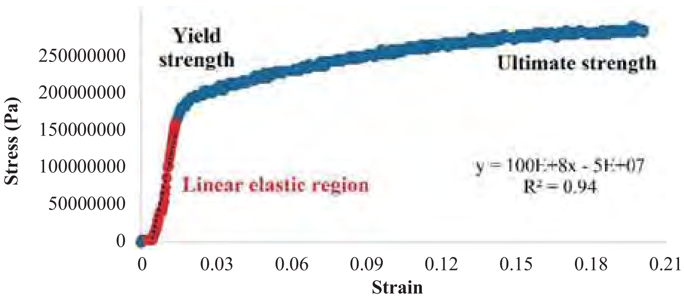
Stress-strain curve of a wire

Stress-strain curve is a graph that shows the change in the stress as stain increases. There are several stages showing different behaviors, which suggest different mechanical properties: (1) the linear elastic region where the slope is Young's modulus, (2) the region where the strain increase rapidly: from Yield strength until the Ultimate strengths, and (3) the necking region until the fracture point.

Material to be tested:

Copper wire
Radius of the wire
$r = 0.000497\ m$
Initial length of the wire
$L = 198.5\ mm$

Elongation (mm)	Force (N)	Strain	Stress (Pa)
0	-27.6	0	0
0.07	-27.7	0.00035264	2575200.41
0.14	-27.7	[illegible]	[illegible]
39.83	-36.3	0.20065491	224042435
39.9	-36.4	0.20100756	226617636



Determine Young's modulus by deflection of a beam

Young's modulus or the modulus of elasticity Y in tension is a mechanical property that measured the tensile stiffness of a solid material. The stress is the force per unit area causing a deformation; strain is a measure of the amount of the deformation. If a stress is applied to a beam to deflect it within its elastic region, the resulting curvature H can be estimated as:

$$H = \frac{FL^3}{4YBt^3}$$

Here:

F is the bending force,
L is the distance between two fulcrum points,
B is the width of the object, and
t is the thickness of the object.

From this equation, the Young's modulus can be obtained experimentally as plotting the force F as a function of the $\frac{4HBt^3}{L^3}$:

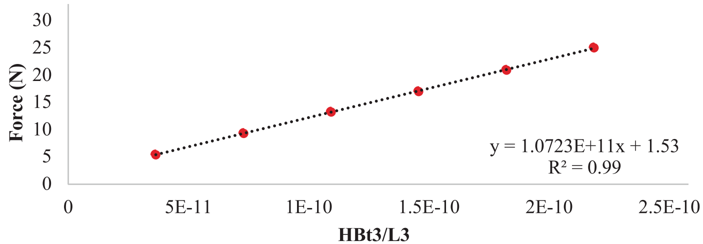
$$F = Y\frac{4HBt^3}{L^3} = slope\frac{4HBt^3}{L^3}$$

The Young's modulus of a material with different impact points and the effect of the length and thickness of the material can be investigated. Moreover, a commercial object's Y can be measured to verify its material.

Material to be tested:

Object: Brass beam
Thickness $t = 0.001\ m$
Width $B = 0.025\ m$
Distance between
two fulcrum points $L = 0.14\ m$

Curvature H (m)	$\frac{4HBt^3}{L^3}$	Force F (N)
0.001	3.64431E-11	5.42
0.002	7.28863E-11	9.42
0.003	1.09329E-10	13.28
0.004	1.45773E-10	17.08
0.005	1.82216E-10	20.98
0.006	2.18659E-10	25.08



Young's Modulus of brass:

$Y_{experimental} = 107.2\ GPa$

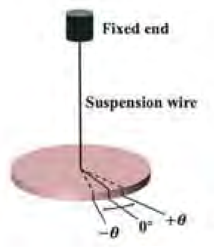
Theoretical range: $Y_{theoretical} = 102 - 125\ GPa$

F12 Torsion Pendulum and Compound Pendulum

Experiments:

1. Torsion pendulum
2. Compound pendulum

Torsion pendulum: "Shear Modulus of metal wires"



When a rigid body is bound to a metal wire, it rotates back and forth due to the spring force of the metal wire. The steel wire exerts a torque on the body as the body is twisted at a small angle θ, and it can be written as:

$$\tau = -K\theta$$

On the other hand, the relationship between the moment of inertia and the period of simple harmonic motion of the body is:

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{I}{K}}$$

From the previous equations, the coefficient K can be derived by calculating the moment of inertia of the body.

Moment of inertia

<u>Disc</u>

$$I = \frac{1}{2}m_1R^2$$

<u>Disc and ring</u>

$$I = \frac{1}{2}m_1R^2 + \frac{1}{2}m_2(R_{in}^2 + R_{out}^2)$$

Finally, the coefficient of rigidity or shear modulus μ can be found:

$$\mu = \frac{2lK\theta}{\pi\theta r^4} = \frac{2lK}{\pi r^4}$$

Length of the metal wire l=500 mm
Disc $m_1 = 1053\ g$;
Ring $m_2 = 486.2\ g$; R_{out} =62.5 mm and R_{in} =52.5 mm

Metal wire	r	Disc			Disc and ring			$\mu(GPa)$		Error
	mm	$T\ (s)$	K	$\mu(GPa)$	$T\ (s)$	K	$\mu(GPa)$	Exp	Theo	%
Stainless steel	1.01	0.54	0.27	81.2	0.75	0.25	76.8	79.0	77.5	**1.9**
	0.75	0.95	0.08	84.83	1.31	0.08	80.5	82.7		**6.7**
	0.51	2.17	0.01	78.14	3.00	0.01	73.5	75.8		**2.1**
Aluminum	1.01	0.93	0.09	26.1	1.27	0.08	24.9	25.5	26.0	**1.7**
Brass	0.99	0.84	0.11	37.2	1.16	0.10	35.1	36.2	37.0	**2.1**

Compound pendulum: "Gravitational acceleration"

Hanging and swinging an object with uneven mass distribution is called a compound pendulum the oscillation period is:

$$T = 2\pi\sqrt{\frac{I}{MgL}}$$

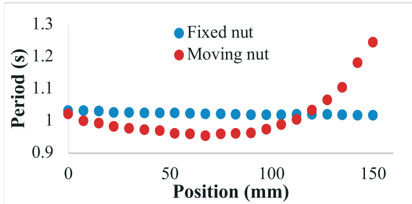
Here: I is the moment of inertia of the object;
M is the mass of the object;
L is the distance of the mass center;

By the Parallel Axis Theorem, periods measured at different positions (distance h_1 and h_2 away from the center of mass) are:

$$T_1 = 2\pi\sqrt{\frac{I_1+Mh_1{}^2}{Mgh_1}} \text{ and } T_2 = 2\pi\sqrt{\frac{I_2+Mh_2{}^2}{Mgh_2}}$$

Moreover, if T_1 is equal to T_2 ($T_0 = T_1 = T_2$), we can get:

$$g = \frac{4\pi^2 L}{T_0^2}, \text{ and here: } L = h_1 + h_2$$



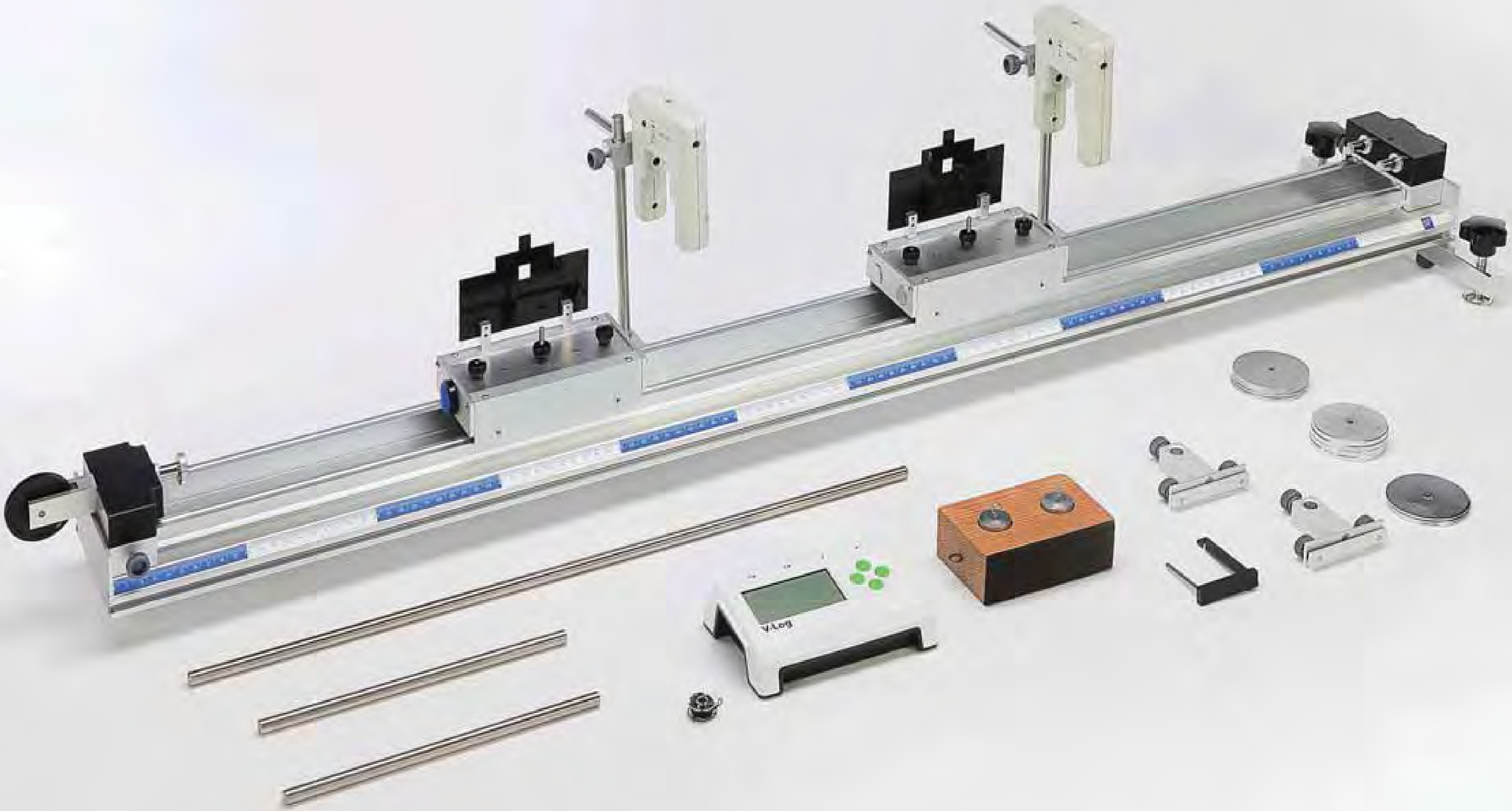
By altering the position of the center of mass and measure respective periods to measure gravitational acceleration:

Number of threads	Position (mm)	Period (s)					
		Nut (fixed)			Nut (moving)		
		1	2	Average	1	2	Average
0	0	1.033	1.032	1.0325	1.024	1.023	1.0235
5	7.5	1.033	1.032	1.0325	[illegible]	[illegible]	[illegible]
95	142.5	1.019	1.018	1.0185	1.183	1.182	1.1825
100	150	1.019	1.018	1.0185	1.246	1.245	1.2455

$T_0 = 1.028\ s$ and $L_0 = 199.5\ mm$
$L_1 = 190\ mm$
$L_2 = 190 - 116.75 = 73.75\ mm$

$$g_{experimental} = \frac{4\pi^2 L}{T_0^2} = \frac{4*3.14^2*(0.19m+0.7375m)}{1.028^2 s^2} = 9.842\frac{m}{s^2}$$

The error of the experiment: 0.43%


V-Log

F27 Newton's Laws of Motion and Friction

Experiments:

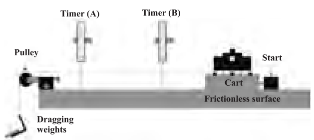
1. Newton's Second Law
2. Inclined plane experiment
3. Collision experiments:
   Elastic collision
   Perfectly inelastic collision
4. Frictional force:
   Maximum static friction
   Kinetic friction

Example:

Newton's Second Law:

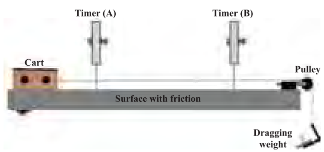
The mass of the block in rest is m_1, the mass of the dragging block is m_2, then the acceleration:

$$a = \frac{m_2 g}{m_1 + m_2}$$



Mass		Empty	$+10\ g$	$+50\ g$	$+100\ g$
Cart		0.32	0.32	0.32	0.32
Weight		0.02	0.03	0.07	0.12
a_{theor}	$\frac{m}{s^2}$	0.56	0.82	1.72	2.63
a_{exper}		0.57	0.83	1.77	2.70
		0.57	0.83	1.76	2.71
		0.56	0.82	1.78	2.74
$\bar{a}_{exper}$		0.57	0.83	1.77	2.72
Error		**0.96%**	**1.2%**	**2.5%**	**3.4%**

Frictional force:



Kinetic coefficient of friction:

$$\mu_k = \frac{m_2 g - a(m_1 + m_2)}{m_1 g}$$

	Wooden $0.039 kg/cm^2$			Wooden $0.058 kg/cm^2$			EVA		
$m\ kg$	$+250\ g$	$+300\ g$	$+350\ g$	$+250\ g$	$+300\ g$	$+350\ g$	$+250\ g$	$+300\ g$	$+350\ g$
$a\ m/s^2$	1.25	2.04	2.86	1.25	2.04	2.86	1.25	2.04	2.86
	1.22	2.07	2.83	1.22	2.07	2.83	1.22	2.07	2.83
	1.25	2.05	2.78	1.25	2.05	2.78	1.25	2.05	2.78
$\bar{a}\ m/s^2$	1.24	2.05	2.82	1.24	2.05	2.82	1.24	2.05	2.82
μ_k	**0.99**	**1.03**	**1.04**	**0.99**	**1.03**	**1.04**	**0.99**	**1.03**	**1.04**

Collision experiments:

If two bodies m_1 and m_2 have velocities v_1 and v_2 before the collision and get the velocities u_1 and u_1 after the collision:

	Before	After
Momentum	$m_1 v_1 + m_2 v_2$	$m_1 u_1 + m_2 u_2$
Kinetic energy	$\frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$	$\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2$

The coefficient of restitution:

$$e = \frac{u_2 - u_1}{v_1 - v_2}$$

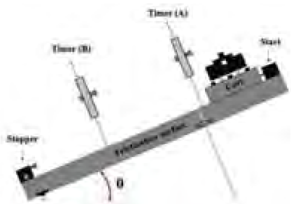
Perfectly inelastic collision				
m_1	kg	0.327	0.829	0.327
m_2		0.327	0.327	0.828
v_1	$\frac{m}{s}$	0.26	0.163	0.27
v_2		0	0	0
u_1		0.113	0.1	0.06
u_2		0.113	0.1	0.06
e		0	0	0
Momentum $kg\ m/s$				
Before		0.085	0.135	0.088
After		0.074	0.116	0.069
Loss %		**13.1**	**14.5**	**21.6**
Kinetic energy J				
Before		0.011	0.011	0.012
After		0.004	0.006	0.002
Loss %		**62.2**	**47.5**	**82.6**

Elastic collision				
m_1	kg	0.327	0.829	0.327
m_2		0.327	0.327	0.828
v_1	$\frac{m}{s}$	0.276	0.633	0.59
v_2		0	0	0
u_1		0	0.24	-0.23
u_2		0.266	0.84	0.303
e		0.96	0.95	0.90
Momentum $kg\ m/s$				
Before		0.090	0.525	0.193
After		0.087	0.474	0.176
Loss %		**3.6**	**9.7**	**9.2**
Kinetic energy J				
Before		0.012	0.166	0.057
After		0.012	0.139	0.047
Loss %		**7.1**	**16.2**	**18.1**

Inclined plane experiment:

The gliding acceleration of the body does not depend on the mass but the angle of inclination as follows:

$$a = g \times \sin\theta$$



Angle of inclination, θ =8.19°					
Mass		empty	$+100\ g$	$+200\ g$	$+400\ g$
a_{theor}	$\frac{m}{s^2}$	$9.8\ m/s^2 \times 8.19° = 1.4$			
a_{exper}		1.34	1.34	1.35	1.34
		1.34	1.34	1.35	1.34
		1.35	1.34	1.35	1.34
$\bar{a}_{exper}$		1.346	1.34	1.35	1.34
Error		**3.4 %**	**4.0 %**	**3.3 %**	**4.1 %**

Experiments:

1. Projectile Motion

1.1. Horizontally launched projectile

1.2. Non-horizontally launched projectile

2. Inelastic collision- Ballistic Pendulum

3. Elastic Collision

3.1. One-Dimensional elastic collision

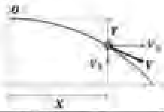
3.2. Two-Dimensional elastic collision

Example:

Horizontally launched projectile:

The constant acceleration due to gravity changes the vertical velocity only and leaves the horizontal velocity unchanged:

$$X = V_0\sqrt{\frac{2Y}{g}}$$



A) Estimated by using a horizontal displacement X:

Height $Y\ (m)$	Horizontal Range, $X\ (m)$ 1	2	3	4	5	Average	Initial speed $V_0\ (\frac{m}{s})$
0.98	1.47	1.46	1.465	1.475	1.47	1.468	**3.282**

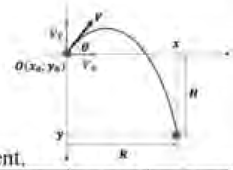
B) By directly measured by a Light gate

Initial speed $V_0\ (\frac{m}{s})$	1	2	3	4	5	Average
	3.473	3.244	3.202	3.235	3.220	**3.274**

Non-horizontally launched projectile:

$$R = x - x_0 = (V_0 cos\theta)t$$

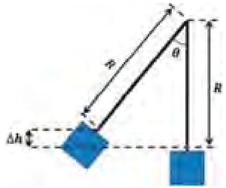
$$H = y - y_0 = (V_0 sin\theta)t - \frac{1}{2}gt^2$$



30° projectile has the highest horizontal displacement.

Angle	10°	15°	30°	45°	60°	70°
Height (m)	1.068	1.07	1.075	1.08	1.085	1.088
Time (s)	0.526	0.558	0.658	0.750	0.815	0.857
Initial speed, $V_0\ (\frac{m}{s})$	3.16	3.16	3.19	3.16	3.08	3.12
$R_{experimental}\ (m)$	1.61	1.68	1.75	1.65	1.37	0.86
$R_{theoretical}\ (m)$	1.63	1.70	1.82	1.68	1.25	0.91
Error, %	1.4	1.2	3.8	1.5	9.3	6.0

Inelastic collision: "Ballistic pendulum"



When a ball strikes at the ballistic pendulum bob and lifts it from the bottom, as shown in the figure, the initial speed of the ball is:

$$v_b = \frac{M}{m_b} \times \sqrt{2g \times R \times (1 - cos\theta)}$$

M is the total mass of the pendulum and the ball:

$$M = m_p + m_b$$

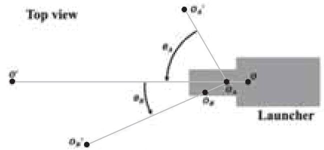
M	Angle (°) 1	2	3	Average	$cos\theta$	$v_b\ (\frac{m}{s})$ Estimated	Measured	Error %
$+0g$	4.8	4.8	5.0	4.9	0.996	4.547	4.534	0.3
$+5g$	4.4	4.6	4.4	4.5	0.997	4.268		5.9
$+10g$	4.4	4.4	4.4	4.4	0.997	4.298		5.2
$+15g$	4.2	4.4	4.4	4.3	0.997	4.324		4.6
$+20g$	4.2	4.2	4.2	4.2	0.997	4.281		5.6

Two-dimensional elastic collision:

In oblique collisions, although the final motion of the bodies would not stick to their initial directions, their total momentum P still conserve.

Suppose *Ball A* with initial speed v_A and m_A collide with a resting *Ball B.*

Then the initial momentum before the collision P_X and P_Y is:



$P_X = P_{AX} = m_A v_A = \mathbf{186.98}\ \mathrm{g}\frac{m}{s}$;

$P_Y = P_{AY} = \mathbf{0}\ \mathrm{g}\frac{m}{s}$

Ball	R (m)	H (m)	$\theta_A(°)$	$v'\ (\frac{m}{s})$	$P'_X = mv'cos\theta\ (\mathrm{g}\frac{m}{s})$	$P'_{AY} = mv'sin\theta\ (\mathrm{g}\frac{m}{s})$
A	0.36	1.068	59.5	1.11	**36.41**	**61.50**
B	0.785	1.068	24.5	2.39	**139.55**	**-63.86**

Then the final total momentum after the collision P'_X and P'_Y can be estimated as:

$P'_X = P'_{AX} + P_{BX} = \mathbf{175.966}\ \mathrm{g}\frac{m}{s}$; $P'_Y = P'_{AY} + P'_{BY} = \mathbf{2.352}\ \mathrm{g}\frac{m}{s}$



Experiments:

1. Mathematical pendulum
2. Free fall
3. Harmonic motion
   - 3.1. Simple harmonic motion: Hooke's Law
   - 3.2. Damped harmonic motion

Example:

Mathematical pendulum:

The period of swing of a simple gravity pendulum depends on its length and it is independent of the mass of the bob. Therefore, the gravitational acceleration is:

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

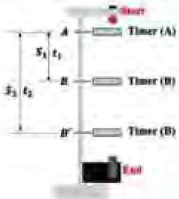
Length of the wire $L = 30\ cm$:

Ball	Average period T swinging 50 times $(second/time)$				Gravitational acceleration $g\ (\frac{m}{sec^2})$		Error %
	1.	2.	3.	Aver.	Experimental	Theoretical	
Small iron ball $(60g; 8cm^3)$	1.091	1.096	1.097	1.095	9.87	9.81	**0.7**
Small plastic ball $(17g; 8cm^3)$	1.265	1.269	1.267	1.267	9.81		**0.1**
Big plastic ball $(17g; 17cm^3)$	1.099	1.099	1.100	1.100	9.77		**0.2**

Free fall:

In Newtonian physics, free fall is any motion of a body falling under the sole influence of gravity. Therefore, the gravitational acceleration is can be found as:

$$g = \frac{2(S_2 t_1 - S_1 t_2)}{t_1 t_2 (t_2 - t_1)}$$



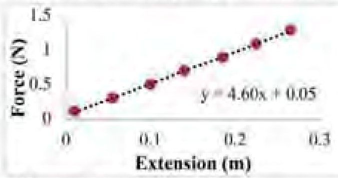
S_1 =0.2 m and S_2 =0.4 m

Ball	Elapsed time, sec		Gravitational acceleration, $\frac{m}{s^2}$		Error %
	t_1	t_2	Experimental	Theoretical	
Small iron ball $(60g; 8cm^3)$	0.1493	0.2303	9.80	9.81	0.04
Small plastic ball $(17g; 8cm^3)$	0.1494	0.2306	9.75		0.4
Big plastic ball $(17g; 17cm^3)$	0.1611	0.2436	9.70		0.9

Simple harmonic motion:

"Static method"

If we plot the dragging force as a function of the spring extension, the slope will be the spring constant, k according to Hooke's Law:



Initial length: $l_0 = 0.005\ m$

$m_{spring} = 0.0095\ kg$

Spring constant found statically is:

$$k_s = 4.60$$

"Dynamic method"

Spring constant can be dynamically determined as:

$$k = 4\pi^2 \frac{m + m_{string}}{T^2}$$

Mass of the spring and weight: $m_{spring} = 0.0095\ kg$ and $m = 0.14\ kg$

Period T (s)						Spring constant k_d
1	2	3	4	5	Aver.	
1.108	1.118	1.117	1.107	1.103	1.111	**4.47**

Damped harmonic motion:

In the air

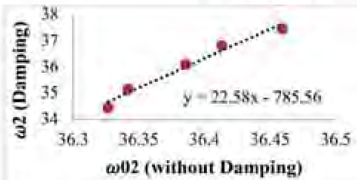
In the water

Damped harmonic oscillators are vibrating systems for which the amplitude of vibration decreases over time.

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{\omega_0^2 - \beta^2}}$$

Frequencies with ω and without ω_0 damping are:

$$\omega^2 = \omega_0^2 - \beta^2$$



Mass of the spring: $m = 0.12\ kg$

Intercept: $\beta^2 = (\frac{b}{2m})^2 = 741.2$

Estimated damping coefficient is:

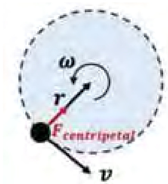
$$b = 6.53$$

Experiments:

1. Centripetal Force
2. Rotational inertia

Example:

Centripetal Force:



When the body with mass m moves in a circular path with radius r with constant speed v, the magnitude of centripetal acceleration a is:

$$a = \frac{v}{r^2}$$

According to Newton's Second Law, the relation between the magnitude of centripetal force F, body's mass m, tangential speed v, rotational period T, radius r and angular speed ω are:

$$F = \frac{mv^2}{r} = mr\omega^2$$

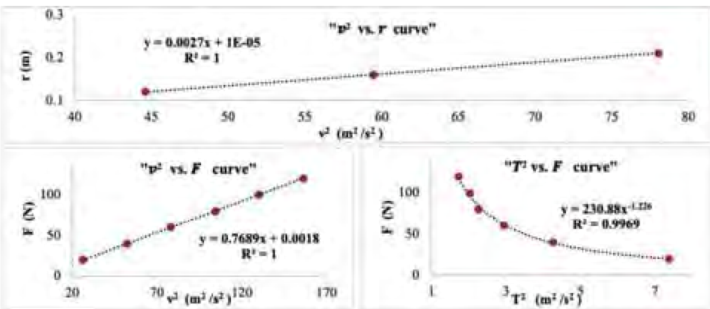
Furthermore, the tangential speed is $v = \omega r$, which can be derived from the period T of circular motion：

$$v = \omega r = \frac{2\pi r}{T}$$

Therefore, the relation between centripetal force F and period T is:

$$F = \frac{(4\pi^2 mr)}{T^2}$$

All of those relationships can be proved experimentally as follows:



Rotational inertia:

According to *Steiner's Theorem* or *Parallel Axis Theorem, the* rotational inertia for the parallel axis is:

$$I_{Parallel} = I_{CM} + md^2$$

If the center of mass won't rotate itself $I_{CM} = 0$, the rotational inertia will be: $I_{Parallel} = md^2$ and in the case of the cylinder rod:

$$I = \frac{MR^2}{4} + \frac{Ml^2}{12}$$

Even when it is empty, the equipment has a particular mass, thus, the rotational inertia. Therefore, the inertia must be determined at first without any object on it.

$$I_{experimental} = I'_{with\ object} - I'_{empty}$$

A) Empty

$M\ (g)$	Period $T\ (s)$				Angular acceleration $\alpha = \frac{8\pi}{T^2}\ (\frac{Rad}{s^2})$	Inertia $I'\ (gcm^2)$
	1	2	3	Aver.		
60	0.612	0.613	0.618	0.614	132.89	17.69

B) With object:

$M\ (g)$	Period $T\ (s)$				Angular acceleration $\alpha = \frac{8\pi}{T^2}\ (\frac{Rad}{s^2})$	Inertia, $I'\ (gcm^2)$
	1	2	3	Aver.		
20	1.90	1.89	1.89	1.89	13.97	56.11
40	1.29	1.28	1.29	1.29	30.12	52.04
60	1.05	1.04	1.04	1.04	45.87	51.27
80	0.90	0.90	0.90	0.90	61.01	51.40
100	0.81	0.80	0.79	0.80	77.55	50.54
120	0.74	0.72	0.74	0.73	92.81	50.68
Average $I'_{with\ object}$						52.01

$$I_{experimental} = I'_{with\ object} - I'_{empty} = 52.01 - 17.69 = 34.31\ gcm^2$$

$$I_{theoretical} = \frac{MR^2}{4} + \frac{Ml^2}{12} = 33.89\ gcm^2$$

The error of the experiment: $\frac{I_{experimental} - I_{theoretical}}{I_{theoretical}} \times 100\% = 1.2\%$

Surface Tension, Viscosity, Capillarity, and Buoyancy

Experiments:

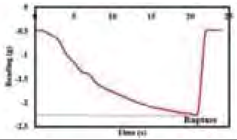
1. Surface tension
2. Viscosity: Poiseuille's Law
3. Capillarity between two plates
4. Density measurement by Buoyancy
   - 4.1. Density of solid
   - 4.2. Density of liquid

Surface tension:

Ring rupture method can determine the surface tension T as:

$$T = \frac{1}{2} \times \frac{F}{l} = \frac{1}{2} \times \frac{F_i - F_f}{\pi d}$$

Here: F_i is the reading before the rupture of the liquid film,
F_f is the reading after the rupture of the liquid film, and
d is the diameter of the measuring ring.



Liquid to be measured:

Distilled water at 30 °C

$T_{theor} = 71.18 \frac{mN}{m}$

$d = 4.15\ cm$

n	Scale reading (g)		Surface tension, T_{exp} ($\frac{mN}{m}$)	Error (%)
	Before rupture	After rupture		
1	-2.346	0.461	70.95	
2	-2.355	0.45	71.71	
3	-2.34	0.485	69.82	
Average surface tension			70.83	0.49

Viscosity: Poiseuille's Law

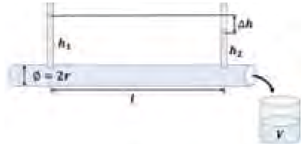
The dynamic viscosity of the liquid μ can be found experimentally as follows:

$$\mu = \frac{\rho g \Delta h \pi r^4}{8lQ}$$

Here: ρ density of the fluid,
$\Delta h = h_1 - h_2$ is the water height difference between two ends,
r is the pipe radius,
l is the length of pipe, and
Q is the volumetric flow rate.

$$Q = \frac{V}{t}$$

Here: V is the volume of the water drained out, and
t is the time required to collect the V amount of water.



Liquid to be measured:

Distilled water at 30 °C

$\rho = 995.6\ kg/m^3$ at T=30°C

$r = 0.0019\ m$ and $l = 0.3\ m$

$\mu_{theor} = 0.79 \times 10^{-3} \frac{Ns}{m^2}$

n	Height (mm)		Δh (m)	V (m^3)	t (s)	Q (m^3/s)	μ_{exp} (Ns/m^2)	Error (%)
	h_1	h_2						
1	44	16.5	0.027	0.0004	76.0	5.26E-06	0.87E-03	
2	43	15.5	0.027	0.0004	71.6	5.58E-06	0.82E-03	
3	43	15	0.028	0.0003	53.7	5.59E-06	0.83E-03	
Average							**0.84E-03**	**6.3**

Capillarity between two plates:

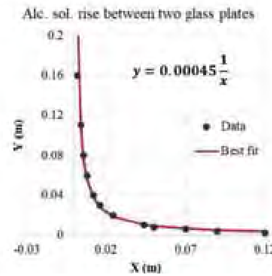
If two glass plates are clamped together as one end is clamped together and the other side clamps a thin rod to make an opening angle θ, the height y of the water at position x is given:

$$y = \frac{2T\cos\alpha}{\rho g \theta} * \frac{1}{x} = slope * \frac{1}{x}$$

Here:
T is the surface tension,
α is the contact angle,
ρ is the density of the fluid, and
θ is the opening angle

$$\theta = \frac{d}{x}$$

Here:
x is the position, and
d is the thickness of the object.

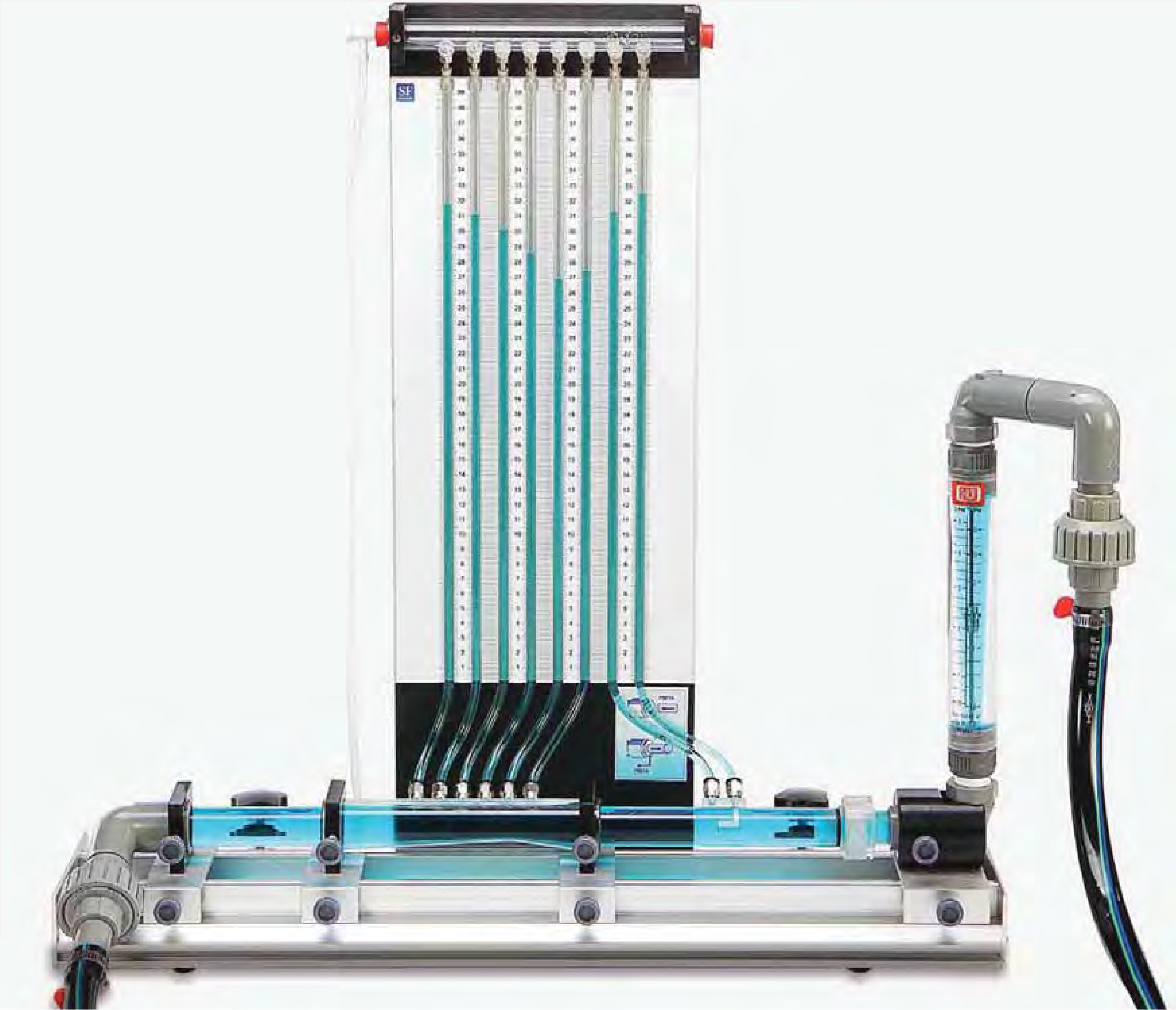


Liquid to be measured:

Alcohol solution at 30 °C (75% Ethanol)
$\rho = 873.9\ kg/m^3$; $\theta = 0.0013$; α =20°

$$T_{exp} = \frac{0.00045 * \rho g \theta}{2\cos\alpha} = 27.36 \frac{mN}{s}; \text{ and } T_{theor} = 27 \frac{mN}{s} \text{ at T=30°C}$$

The error of the experiment = 1.3 %



Experiments:

1. Measure the flow rate by Pitot tube
2. Measure the flow rate by Venturi tube

Example

Bernoulli's equation states that the sum of the pressure P; kinetic energy per unit volume $\frac{1}{2}\rho v^2$; and the potential energy per unit volume ρgh; has the same value at all points along a streamline.

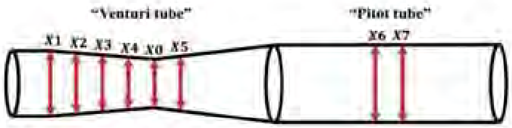
$$P + \frac{1}{2}\rho v^2 + \rho gh = constant$$

In this equation:
P is the pressure;
ρ is density;
v is velocity;
g is gravitational acceleration; and
h is the height of fluid (from a reference point).

The equation of Continuity of an incompressible fluid, $\rho_1 = \rho_2$ is:

$$Q = A_1 v_1 = A_0 v_0$$

Q is called the *flow rate* and has dimensions of volume per unit time.



The velocity at cross-section A_0:

$$v_0 = \sqrt{\frac{2g(h_1 - h_0)}{1 - \left(\frac{A_0}{A_1}\right)^2}}$$

The flow rate of cross-section A_0 is:

$$Q = A_0 \times \sqrt{\frac{2g(h_1 - h_0)}{1 - \left(\frac{A_0}{A_1}\right)^2}}$$

Measure the flow rate by Pitot tube:

It is used to measure local velocity at any fixed point instead of the average velocity of the whole pipeline.

$$v_{pitot} = \sqrt{2g(h_7 - h_6)} = 61.056\,\frac{cm}{s}$$

Therefore:

$$Q_{Pitot} = v_{Pitot} * A_6 = 12.93\ LPM$$

The theoretical velocity at each section will be calculated as follows:

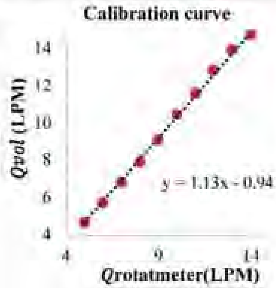
$$A_1 = \pi R^2 = 237.78\ mm^2$$

$$v_1 = \frac{v_{pitot} * A_6}{A_1} = 90.6\,\frac{cm}{s}$$ and so on.

Column		X1	X2	X3	X4	X0	X5
Diameter, Ø (mm)		17.4	16.1	15	13.8	13.1	14.6
Cross-sectional area A_i (mm^2)		237.7	203.5	176.7	149.5	134.7	167.4
Velocity, v_i ($cm\backslash s$)		90.6	105.8	121.9	144.0	159.9	128.7
Flow rate Q_i (LPM)	Experimental	129.2	129.2	129.2	129.2	129.2	129.3
	Theoretical	12.93					
Error (%)		0.07	0.09	0.05	0.10	0.05	0.03

Measure the flow rate by Venturi tube

The speed is adjusted to: $Q_{rot} = 11\ LPM$, which is actually $Q_{vol} = 11.65\ LPM$ according to the calibration curve.



Note that we chose $X1$ column as a reference to estimate the rest of the local velocity.

$$v_2 = \sqrt{\frac{2g(h_1 - h_2)}{1 - \left(\frac{A_2}{A_1}\right)^2}} = =89.97\,\frac{cm}{s}$$ and so on.

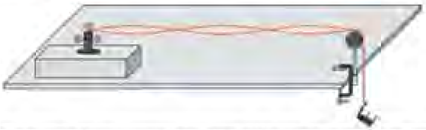
Column		X1	X2	X3	X4	X0	X5
Cross-sectional area, A_i (mm^2)		237.7	203.5	176.7	149.5	134.7	167.4
Height of the column, h (cm)		29	27.9	26.3	23.9	21.2	22.5
Velocity, v_i ($cm\backslash s$)		-	89.9	108.7	128.6	150.1	111.9
Flow rate Q_i (LPM)	Experimental	-	10.9	11.5	11.5	12.1	11.2
	Theoretical	11.65					
Error (%)		-	6.4	1.2	1.2	3.8	3.8


Sine Wave
Generator
5390
Frequency
8
AMPL.

Experiments:

1. Resonant property and frequency of standing wave
2. Chladni plates
3. Standing wave in Bohr's atomic model
4. Transverse oscillation of cantilever beam
5. Longitudinal oscillation of spring

Resonant property and frequency of standing wave: Driving frequency, density, and tension of the string are varied to explore standing waves in strings and to determine the speed of the wave



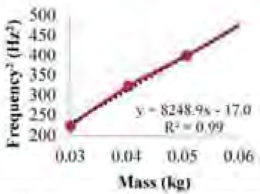
Single layer string:
$m_{string} = 0.55\ g$
$L = 1\ m$
$m_{weight} = 60\ g$

$f\ (Hz)$	Segment	1	2	3	4	5	6	7	8	9	λ/2 (cm)	Exp $v\ (m/s)$	Theo $v\ (m/s)$
22	1	100									100	440.00	425.41
66	3	33	34	34							33.33	440.00	425.41
108	5	19	20	21	21	21					20	432.00	425.41
153	7	14	15	14	14	15	15	15			14.29	437.14	425.41
196	9	11	11	12	11	11	12	11	11	11	11.11	435.56	425.41
Average speed of wave $v\ [m/s]$												435.82	425.41

String density can be found from the driving frequency, hanging weight and length of the string:

Since $v = \lambda f$ and $v = \sqrt{F/\mu}$, then

$$f^2 = \frac{mg}{\mu\left(\frac{2L}{n}\right)^2};\ \mu = \frac{m}{f^2}\frac{n^2 g}{4L^2}$$

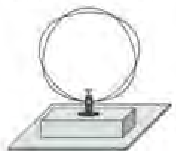


	Frequency $f\ (Hz)$				Slope	Density	Error	Average
n	$30g$	$40g$	$50g$	$60g$	(Hz^2/kg)	(g/m)	(%)	Density
2	29	35	40	43	32874	0.30	9.76	$0.31g/m$
4	61	72	79	88	126927	0.31	6.51	
6	87	104	118	129	293272	0.30	8.96	Average Error
8	125	143	160	175	485026	0.32	2.13	6.14%
10	154	178	199	218	767317	0.32	3.34	

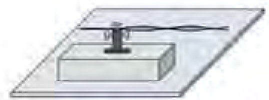
Chladni plates: Visualization of two-dimensional standing wave patterns on circular and square plates.

Demonstrations:

Standing wave in Bohr's atomic model



Transverse oscillation of cantilever beam



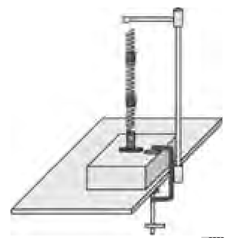
Longitudinal oscillation of spring: Determination of the resonance frequency of spring using the spring constant and its weight.

Relationship of resonance frequency and spring constant:

$$f_n = \frac{n}{2}\sqrt{\frac{k}{m}}$$

$m = 9.44\ g$
$k = 4.75\ N/m$

n	Experimental $f\ (Hz)$	Theoretical f_n (Hz)	Error %
1	11	11.21	1.91
3	33	33.64	1.91
5	57	56.07	1.65
7	80	78.50	1.91




Resonance Tube Experiment
570

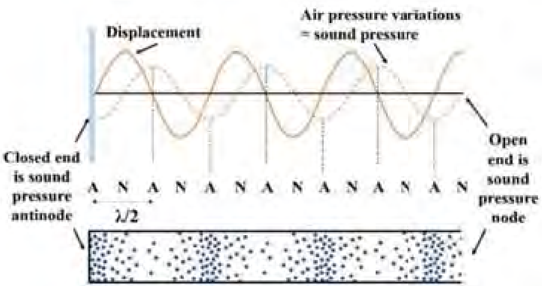
Experiments:

1. Wavelength of sound in open and closed tubes
2. Speed of sound

The sound wave travels along the resonance tube length and is reflected from the other end of the tube and travels back to the horn. When the tube length is integer multiple of the wavelength of the sound waves, the waves are in resonance and standing waves are created. The Styrofoam beads show the feature of standing waves by compression of air inside the tube.

The theoretical speed of sound:

$$v_s = f\lambda$$

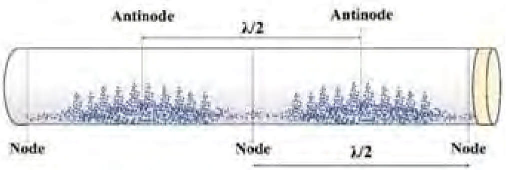


Speed of sound in the air is dependent on the temperature:

$$v_s = 331.4 + 0.606T\ [m/s]$$

The tube length and wavelength of sound waves are related by:

$$\text{Closed: } L = \frac{n\lambda}{4}, n = 1, 3, 5, 7, \ldots \quad \text{Open: } L = \frac{n\lambda}{2}, n = 1, 2, 3, 4, \ldots$$



Wavelength and speed of the light determined by varying the frequency:

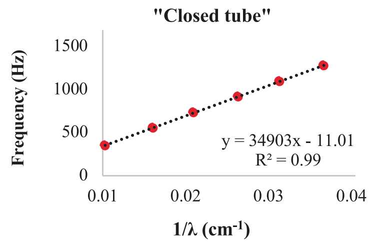
	$f(Hz)$	Overtones	λ	v_s (theo)	v_s (exp)	Error %	
Closed tube	350	2	97	204.92	339.50	52.66	Average speed of light 346.62 m/s
	556	3	62.2	62.66	345.83	0.73	
	733	4	47.67	47.53	349.40	0.30	
	915	5	37.95	38.07	347.24	0.32	Average error 7.89%
	1096	6	31.88	31.79	349.40	0.30	
	1280	7	27.27	27.22	349.01	0.19	
	1464	8	23.63	23.80	345.92	0.70	

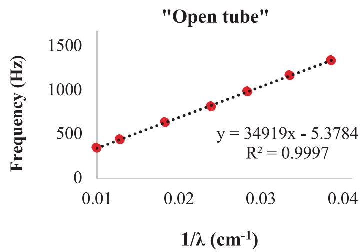
	$f(Hz)$	Overtones	λ	v_s (theo)	v_s (exp)	Error %	
Open tube	348	2	100	100.11	348.00	0.11	Average speed of light 346.59 m/s
	440	3	78	79.17	343.20	1.48	
	640	4	54.5	54.43	348.80	0.06	
	816	5	41.8	42.69	341.09	2.09	Average error 0.63%
	987	6	35.25	35.30	347.92	0.13	
	1173	7	29.8	29.70	349.55	0.34	
	1342	8	25.9	25.96	347.58	0.23	

The theoretical value of the speed of sound at 28°C: 348.37 m/s

Closed tube:

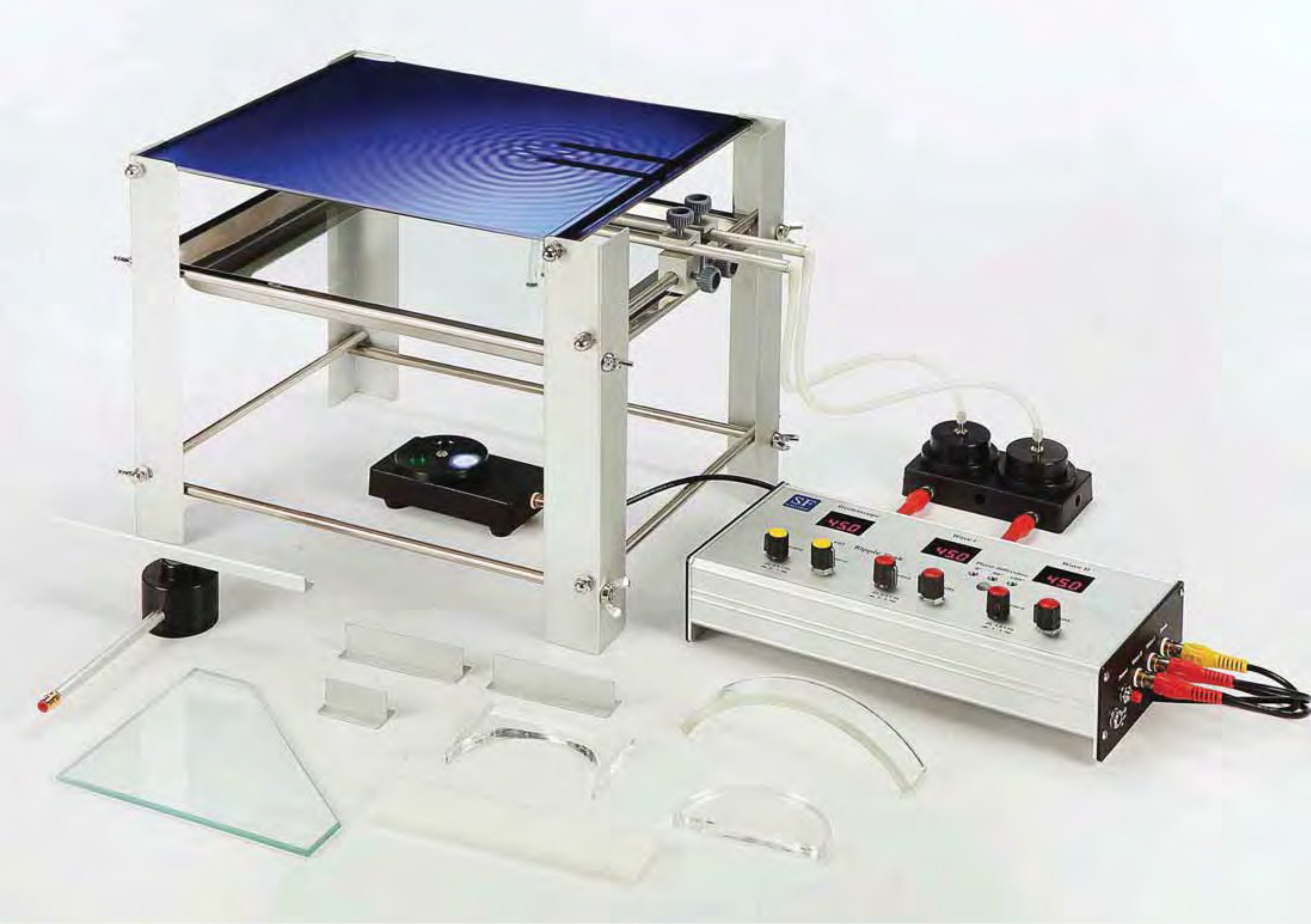
Speed of sound found from the slope = 349.03 m/s
Experimental error = 0.19%





Open tube:

Speed of sound found from the slope = 349.19 m/s
Experimental error = 0.24%


45.0
45.0
45.0

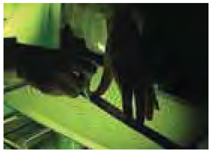
F05 Ripple Tank

Experiments:

1. Circular wave
2. Plane wave
3. Reflection of waves
3.1. Reflective baffle
3.2. Concave and convex mirrors
4. Refraction of waves
4.1. Trapezoid refractive glass plate
4.2. Concave and convex lenses
5. Diffraction of waves
6. Interference of waves
6.1. Ripple stopper
6.2. Dual-source waves
7. Dual-source interference
8. Wave demonstrations
- Frequency beats
- Phased array
- Dipole source
- Doppler Effect and Sonic boom
- Lloyd's mirror

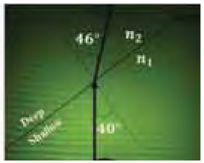
Example:

The black screen on top enables the quantitative study by directly drawing the waves on it. Moreover, it protects the eye from direct glare as maintaining the optimal contrast.

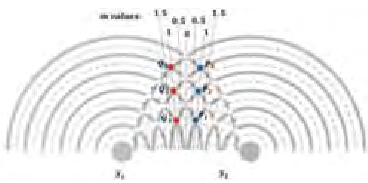


Refractions of waves:

Wave propagation through different medium with different refractive indices results in the change in the angle and wavelength.



$$\frac{n_1}{n_2} = \frac{sin\theta_2}{sin\theta_1} = \frac{sin46°}{sin40°} = 1.119$$



Interference of waves:

The path difference PD is:

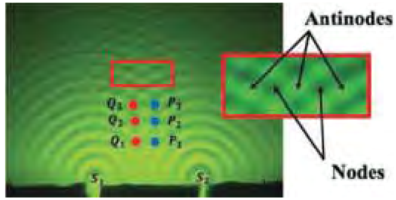
<u>*At Antinode:*</u>

$PD = m\lambda \ (m = 0, 1, 2, \ldots)$

<u>*At Node:*</u>

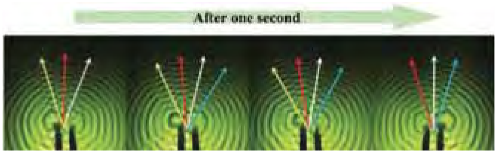
$PD = m\lambda \ (m = 0.5, 1.5, 2.5, \ldots)$

Path difference $PD = \lambda \ (mm)$	
Left side	
$S_2Q_1 - S_1Q_1$	9
$S_2Q_2 - S_1Q_2$	9
$S_2Q_3 - S_1Q_3$	9
Right side	
$S_1P_1 - S_2P_1$	8
$S_1P_2 - S_2P_2$	8.5
$S_1P_3 - S_2P_3$	8.75
Average	**8.7**



Wave demonstrations:

"Frequency beats"



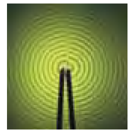
A source: $f_1 = 45 \ Hz$
B source: $f_2 = 44 \ Hz$
$f_{beats} = f_1 - f_2 = 1 \ Hz$
Period $T = \frac{1}{f_{beats}} = 1 \ sec$

"Phased array antenna"

Phase difference causes the propagating directions of the wavefront to change.

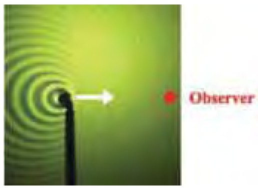
"Dipole source"

Adjacent two-point sources 180° out of phase:



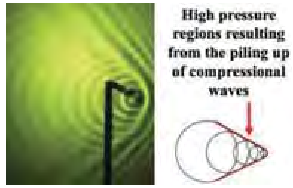
"Doppler effect"

Change in wavelength in relation to an observer who is moving relative to the wave source.

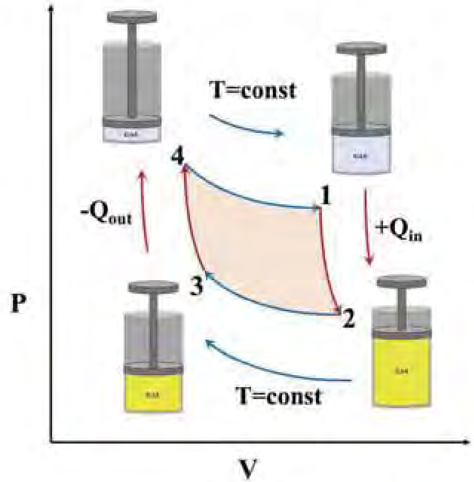


"Sonic boom"

Happens when the source moves faster than the wave that it is generating.



"CARNOT CYCLE"



Two Adiabatic **Two Isothermal**

Word done = $Area$

Efficiency= $\frac{Area}{Q_{in}}$

Experiments:

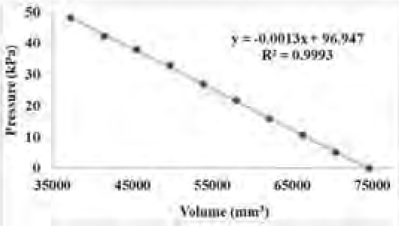
1. Boyle's Law
2. Charles and Gay-Lussac's Law
3. Combined gas Law
4. Carnot cycle
5. Ratio of Specific heat

Example:

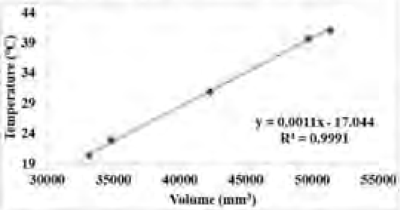
Boyle's Law:

The pressure (P) of a given mass of an ideal gas is inversely proportional to its volume (V) at a constant temperature.

$$P_1V_1 = P_2V_2$$



Charles and Gay-Lussac's Law:



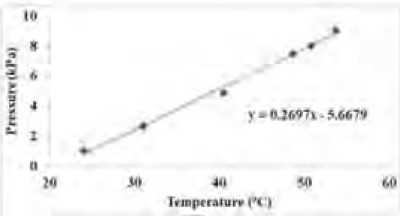
If the pressure (P) is held constant, the volume (V) is equal to constant times the temperature.

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

Combined gas Law of Thermodynamics:

For a given mass and a constant volume of an ideal gas, the pressure (P) exerted on the sides of its container is directly proportional to its absolute temperature (T).

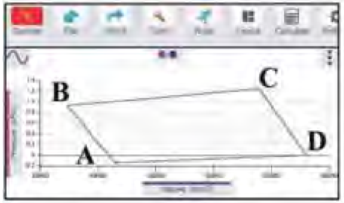
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$



Heat engine to demo "Carnot cycle":

In a complete cycle of Carnot's heat engine, the gas traces the path **ABCD**. The work done by an engine undergoing the cycle is given:

$$W = \int PdV = \int_a^b PdV + \int_b^c PdV + \int_c^d PdV + \int_d^a PdV$$



A to **B** and **C** to **D**: *Adiabatic processes*

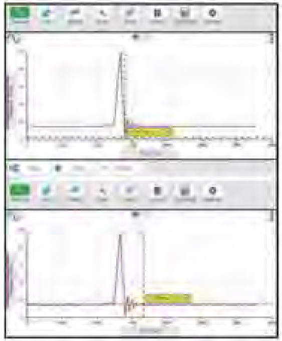
B to **C** and **D** to **A**: *Isothermal processes*

Ratio of Specific heat:

The ratio of the specific heat of a gas γ:

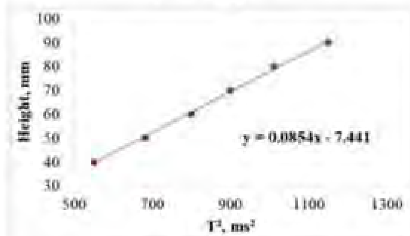
$$\gamma = \frac{C_V}{C_P}$$

Here: C_V is the heat capacity at constant volume; and
C_P is the heat capacity at constant pressure.



It can be estimated by the measuring period of the piston oscillation from the experiment:

$$\gamma = \frac{4\pi^2 m(slope)}{AP}$$



$$\gamma_{experimental} = \frac{4 \cdot 3.14^2 \cdot 0.035kg \cdot 0.085 \cdot \frac{10^{-3}m}{10^{-6}s^2}}{3.14 \cdot 16.25^2 \cdot 10^{-6}m^2 \cdot 101.01 \cdot 10^3 Pa} = 1.4008$$

Theoretical ratio of the specific heat of air at 30°C: **1.401**


SF
AC & DC POWER SUPPLY
DUAL THERMOMETER

Experiments:

1. Linear Thermal expansion
2. Specific heat
3. Equivalent of heat

Linear Thermal expansion:

Thermal Expansion coefficient α shows the tendency of matter to change its shape and volume in response to a change in temperature.

$$\alpha = \frac{\Delta l}{l_0 \cdot \Delta T} = \frac{\Delta l}{l_0 \cdot (T_2 - T_1)}$$

Here: l_0 is the initial length of the rod;
Δl is the expansion value; and
T_1 and T_2 is the rod temperature before and after the heating

	Δl,mm	T_1,°C	T_2,°C	$T_{average}$,°C	ΔT,°C	$l_0\Delta T$	$(X-\bar{X})$	$(Y-\bar{Y})$	$(X-\bar{X})^2$	$(Y-\bar{Y})^2$	$(X-\bar{X})(Y-\bar{Y})$
	0.01	36	36	36	4	1840	-14703.953	-0.21	216206248.2	0.0441	3087.830233
	0.02	37	38	37.5	5.5	2530	-12863.953	-0.25	165481299.4	0.0625	3215.988733
	0.03	40	40	40	8	3680	-12173.953	-0.24	148205143.5	0.0576	2921.748837
	0.04	41	41	41	9	4140	-11023.953	-0.23	121527550.5	0.0529	2535.509302
	0.05	42	43	42.5	10.5	4830	-10563.953	-0.22	111597113.3	0.0484	2324.069767
	0.06	44	44	44	12	5520	-9873.9535	-0.21	97494957.49	0.0441	2073.530233
	0.07	45	46	45.5	13.5	6210	-9183.9535	[illegible]	[illegible]	[illegible]	[illegible]
	0.08	47	47	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5976.0465	0.09	47811699.35	0.0081	[illegible]
	[illegible]	[illegible]	85	82.5	50.5	23230	7806.0465	0.1	64403624.95	0.01	783.4046512
	0.38	83	85	84	52	23920	8526.0465	0.11	72693469.12	0.0121	937.8651163
	0.39	84	85	84.5	52.5	24150	9256.0465	0.12	84603513.3	0.0144	1101.925581
	0.4	85	86	85.5	53.5	24610	9446.0465	0.13	89227798.7	0.0169	1227.986047
	0.41	86	87	86.5	54.5	25070	9906.0465	0.14	98129757.49	0.0196	1386.846512
	0.42	87	88	87.5	55.5	25530	10366.047	0.15	107456930.5	0.0225	1554.906977
	0.43	87	88	87.5	55.5	25530	10826.047	0.16	117203283.1	0.0256	1732.167442
SUM	9.46					632279			21972785393	0.7462	38479.60233
Mean	0.22					14703.95					

NOTE: "The least square method" is used to increase the accuracy of the result

Object:
Copper rod
$l_0 = 460\ mm$
$T_0 = 32°C$

$$\alpha = \frac{(X-\bar{X})(Y-\bar{Y})}{(X-\bar{X})^2} = 1.7508 * 10^{-5}$$

$$R\ squared, R^2 = \left(\frac{(X-\bar{X})(Y-\bar{Y})}{\sqrt{(X-\bar{X})^2 * (Y-\bar{Y})^2}}\right)^2 = 0.90$$

Thermal Expansion coefficient $\alpha_{experimental}$: $1.75 * 10^{-5}\ °C^{-1}$

Thermal Expansion coefficient $\alpha_{theoretical}$: $1.77 * 10^{-5}\ °C^{-1}$

The error of the experiment: **1.13** %

Specific heat:

Specific heat, also called *heat capacity* C is a physical quantity to show an object's ability to absorb or dissipate heat.

$$Q = m \cdot C \cdot \Delta T = m \cdot C \cdot (T_2 - T_1)$$

Here: Q is the heat required to heat the object;
m is the mass of the object; and
T_1 and T_2 is the temperature before and after the heating.

NOTE: The heat capacity of the water-containing calorimeter without the object must be determined beforehand.

A. <u>Calorimeter with water:</u>

$$C_{cal} = \frac{Q_{cal}}{\Delta T} + C_{water} \cdot m_{water} = 1857.7 \frac{J}{°C}$$

B. <u>Calorimeter with water and the object:</u>

Object: Metal bar

$Q_{cal} = -Q_{bar}$, and it gives: $C_{cal} \cdot \Delta T_{cal} = m_{bar} \cdot C_{bar} \cdot \Delta T_{bar}$

$$C_{bar} = \frac{C_{cal} \cdot \left(T^{final} - T^{initial}_{cal}\right)}{m_{bar} \cdot \left(T^{final} - T^{initial}_{bar}\right)}$$

Metal	$T^{initial}_{cal}$	$m_{bar}(g)$	$T^{initial}_{bar}$	T^{final}	C_{bar} ($J/(g \cdot °C)$)		Error (%)
					Experimental	Theoretical	
Aluminum alloy	31.3	49.48	86.6	32.7	0.97	0.896	**8.2**
Stainless steel	31.5	118.1	88.7	33.2	0.481	0.502	**4.1**
Brass	31.4	126	80.4	32.6	0.370	0.380	**2.6**
Copper	31.8	146.6	84.0	33.3	0.374	0.386	**3.1**

Equivalent of heat:

According to the First Law of Thermodynamics, the work done on a system is transferred into the internal energy as heat and the mechanical equivalent of heat is equal to:

$$J = \frac{W}{Q} = \frac{IVt}{C_{cal}(T_2 - T_1)}$$

Object: Calorimeter with $C_{cal} = 1857.7 \frac{J}{°C}$ at $T_1 = 31\ °C$

	Time,min	T_2,°C	ΔT,°C	W,Joule	Q,Joule	$(X-\bar{X})$	$(Y-\bar{Y})$	$(X-\bar{X})^2$	$(Y-\bar{Y})^2$	$(X-\bar{X})(Y-\bar{Y})$
	1	[illegible]	0.4	1121.28	743.08	-13784.134	-144649	190003150	2.092E+10	1993811025
	2	[illegible]	1	2242.56	1857.7	-12669.514	-143524	160851 [illegible]	2.06E+10	1818380141
	3	[illegible]	1.8	3363.84	3343.86	-11183.354	-142403	125067407	2.028E+10	1592540923
	4	34.2	2.4	4485.12	4458.48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	24150.1	[illegible]	-121099	[illegible]	1.466E+10	-1165316666
	23	45.3	13.5	25789.44	25079.95	[illegible]	-119977	[illegible]	1.439E+10	-1265967740
	24	45.9	14.1	26910.72	26193.57	[illegible]	-118856	136103862	1.413E+10	-1386615475
	25	46.4	14.6	28032	27122.42	[illegible]	-117735	158639214	1.386E+10	-1482892044
SUM				364416	363188.35			1.581E+09	4.319E+11	[illegible]
Mean				14576.64	14527.334					

Current ($I = 2.56A$)
Voltage ($V = 7.3V$)

$$J = \frac{(X-\bar{X})(Y-\bar{Y})}{(X-\bar{X})^2} = 1.02$$

$R\ squared = 0.99$

Equivalent of heat $J_{experimental}$: 1.02

Equivalent of heat $J_{theoretical}$: 1.00

The error of the experiment: **2.22** %


DUAL THERMOMETER
TH 906A
PELTIER EFFECT
SEEBECK EFFECT
POWER INPUT
HEATER

Experiments:

1. Carnot efficiency evaluation
2. Heat engine: Seebeck effect
3. Heat pump: Peltier effect

Example:

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa.

Carnot efficiency evaluation:

Thermoelectric devices create a voltage when there is a different temperature on each side and that temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side. Conversely, when a voltage is applied to it, heat is transferred from one side to the other, creating a temperature difference and named *Seebeck effect* and *Peltier effect*, respectively.

Seebeck effect mode:

$T(K) = T(°C) + 273.15K$

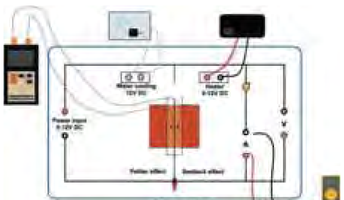
Resistance: 4.4 Ω

$P_W = \frac{V_W^2}{R} = \frac{(0.899V)^2}{4.4\Omega} = 0.184\ W$

$P_H = V_H * I_H = 4V * 2.14A = 8.556\ W$

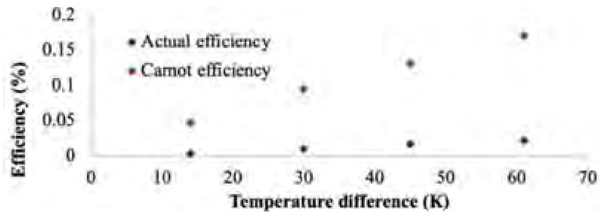
$e_{actual} = \frac{P_W}{P_H} = \frac{0.184\ W}{8.556\ W} = 0.21$

$e_{Carnot} = \frac{\Delta T}{T_{Hot}} = \frac{61K}{351.15K} = 0.17$



Apparatus

$V_H\ (V)$	$I_H\ (A)$	Kelvin		$\Delta T\ (K)$	$V_W(V)$	$P_W(W)$	$P_H(W)$	e_{actual}	e_{Carnot}
		T_{Cold}	T_{Hot}						
4	2.14	290	351	61	0.89	0.184	8.556	0.021	0.17
3.5	1.87	290	335	45	0.69	0.109	6.559	0.016	0.13
3	1.60	289	319	30	0.45	0.046	4.800	0.009	0.094
2.5	1.34	289	303	14	0.21	0.010	3.353	0.003	0.046



Heat engine: Seebeck effect

In this detailed experiment student will determine the Actual efficiency e_{actual} and the Carnot efficiency e_{Carnot} of the heat engine and identify the energy losses in order to show that e_{actual} approaches the e_{Carnot}

Resistance: 4.4 Ω

Mode	Kelvin		$V_H\ (V)$	$I_H\ (A)$	$V_W\ (V)$	$V_S\ (V)$
	T_{Cold}	T_{Hot}				
Heat engine (with load)	289	333	3.5	1.884	0.663	
Open mode	289	333	3	1.6		1.48

$$r = \frac{(V_S - V_W)}{V_W} R = \frac{(1.48\ V - 0.66V)}{0.66V} * 4.4\ \Omega = 5.42\ \Omega$$

Actual Efficiency:

$$e_{actual} = \frac{P_W}{P_H} = \frac{\frac{V_W^2}{R}}{V_H I_H} = \frac{\frac{(0.0.663V)^2}{4.4\Omega}}{3.5V * 1.6A} = \mathbf{0.02}$$

Carnot Efficiency:

$$e_{Carnot} = \frac{\Delta T}{T_{Hot}} = \frac{44K}{333.15K} = \mathbf{0.132}$$

Adjusted Efficiency:

$I_W = \frac{V_W}{R} = \frac{0.663\ V}{4.4\ \Omega} = 0.15\ A$

$P'_W = P_W + {I_W}^2 r = \frac{{V_W}^2}{R} + {I_W}^2 r = 0.099W + (0.15A)^2 * 5.42\Omega = 0.22\ W$

P'_H =available heat=$P_H - P_H(open) = 6.59W - 4.8W = 1.59W$

$$e_{adjusted} = \frac{P'_W}{P'_H} = \frac{P_W + {I_W}^2 r}{P_H - P_{H(OPEN)}} = \frac{0.22\ W}{1.59W} = \mathbf{0.138}$$

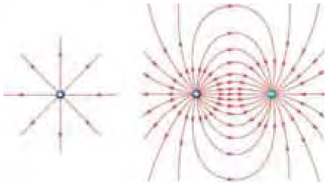
F17 Electric Field Mapping

Experiments

1. Two points within a field
2. Parallel plate capacitor
3. Point charge and plate
4. Lightning rod and plate
5. Electrostatic shielding
6. Three points charges

An electrically charged object will produce an electric field around itself and the electrostatic force can act through space, producing effect even when there isn't any physical contact between objects existing within the produced field.

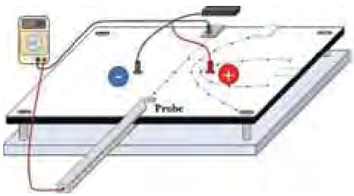
If a point charge with electric quantity q experiences an electric force $\vec{F}$ due to the electric field produced by much larger positive charge Q, the magnitude of the electric field is:



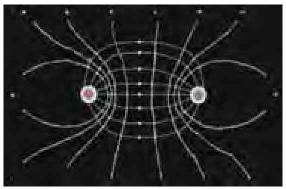
$$\vec{E} = \frac{\vec{F}}{q}$$

Equipotential line and electric field of two charged bodies:

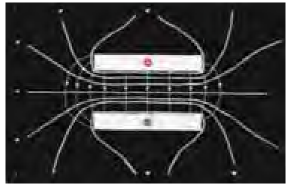
Equipotential line and electric field are mapped for two charged bodies with different shapes. The potential divider is used to map equipotential lines and electric field is the drawn accordingly with equipotential lines.



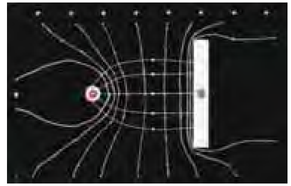
Two point charges



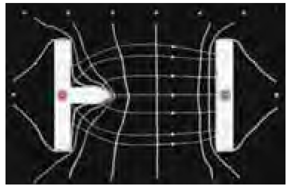
Parallel plate capacitor



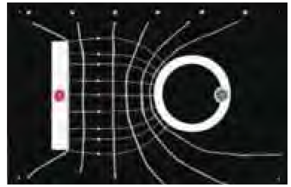
Point charge and plate



Lightning rod and plate

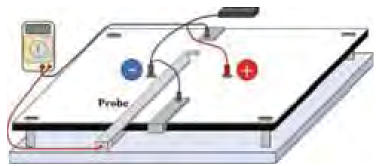


Electrostatic shielding

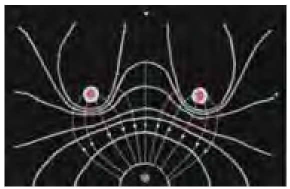


Equipotential line and electric field of three charged bodies:

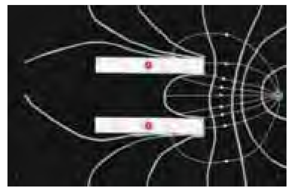
Equipotential line and electric field are mapped for three charged bodies with different shapes to illustrate the electric field for multiple charges.



Three point charges



Parallel plate and point charge



Electrostatic force vs. Gravitational force

In this experiment, the student will set up a horizontal parallel plate capacitor and find the voltage at which a piece of aluminum foil of known dimensions just lifts off the bottom plate and creating a conducting path between the plates. At that moment the electric force then just balances the force of gravity:

$$F_{electric} = F_{gravity} = \rho t A_{foil}\, g$$

On the other hand, the electric force on the foil will be its charge times the electric field it feels. The total field E in between the capacitor is:

$$E = \frac{V}{d} \text{ and, the } E_{top} = \frac{E}{2} = \frac{V}{2d}$$

The magnitude is then given by:

$$F_{electric} = Q_{foil} E_{top} = \sigma A_{foil} \frac{V}{2d} = \varepsilon_0 \frac{V^2 A_{foil}}{2d^2}$$

Equating equations above, the electric and gravitation forces yield:

$$\varepsilon_0 \frac{V^2}{2d^2} = \rho t g$$

Here: ρ is the density of the aluminum foil,
V is the applied voltage, and
d is the spacing between the plates.

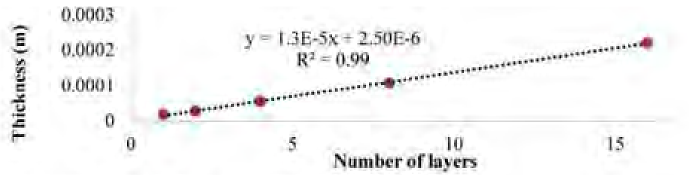
Since $V^2 = \left(\frac{2t\rho g}{\varepsilon_0}\right) d^2$, if you plot V^2 vs. d^2 you should get a straight line whose slope is the coefficient of d^2. You can calculate the free permittivity of space, ε_0 from your experimental value for the slope as follows:

$$\varepsilon_0 = \frac{2\rho g t}{slope}$$

Foil thickness measurement:

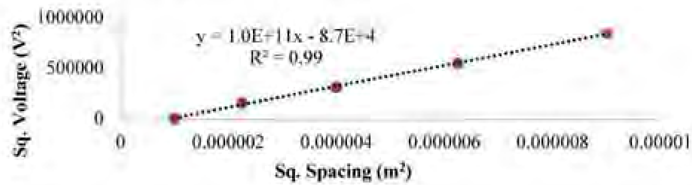
Using screw gauge to measure several layers of film and obtain the thickness as a function layer curve:

Number of layers	Thickness (m)
1	0.000018
2	0.000029
4	0.000057
8	0.00011
16	0.000222



Determination of the permittivity of free space:

Thickness of a single aluminum foil $t = 16.2 \times 10^{-6}\ m$
Density of Aluminum foil $\rho = 2.7 \times 10^3 \frac{kg}{m^3}$
Acceleration due to gravity $g = 9.8\ m/s^2$



Spacing		Voltage (V)						Voltage² (V^2)
d (mm)	d^2 (m^2)	1	2	3	4	5	Average	
1.0	0.00000100	100	100	100	100	100	100	10000
1.5	0.00000225	400	420	400	400	400	404	163216
2.0	0.00000400	550	570	520	580	580	560	313600
2.5	0.00000625	740	720	760	880	620	744	553536
3.0	0.00000900	900	920	900	960	920	920	846400

Slope of the best-fit line: $\mathbf{1.03 \times 10^{11}} \frac{V^2}{m^2}$

According to *Equation. (4)*, the permittivity of free space is:

$$\varepsilon_0 = \frac{2\rho g t}{slope} = \frac{2 \cdot 2700 \frac{kg}{m^3} \cdot 9.8 \frac{m}{s^2} \cdot 16.2 \cdot 10^{-6} m}{1.03 \cdot 10^{11} \frac{V^2}{m^2}} = 8.323 \times 10^{-12} \frac{F}{m}$$

Theoretical $\varepsilon_0 = 8.854 \times 10^{-12} \frac{F}{m}$

The error of the experiment: $\frac{Theoretical\ \varepsilon_0 - Experimental\ \varepsilon_0}{Theoretical\ \varepsilon_0} \times 100\% = 5.9\%$

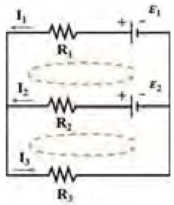

Rx
DC
A
V

Experiments:

1. Ohm's law
2. Series and Parallel resistor
3. Kirchhoff's circuit law
4. Wheatstone bridge
5. Sources of EMF
6. Current-Voltage characteristics of diode
7. The I_C-V_{EB} characteristics of PNP transistor
8. Current amplification of PNP transistor
9. The I_C-V_{CE} characteristic curve of NPN transistor

Examples:

Kirchhoff's circuit law: Determination of current through the circuit with dual voltage source.



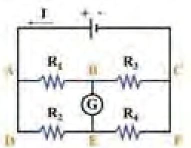
$$I_1 = \frac{\varepsilon_1(R_2 + R_3) - \varepsilon_2 R_3}{R_1R_2 + R_2R_3 + R_3R_1}$$

$$I_2 = \frac{\varepsilon_2(R_1 + R_3) - \varepsilon_1 R_3}{R_1R_2 + R_2R_3 + R_3R_1}$$

$$I_3 = \frac{\varepsilon_1 R_2 - \varepsilon_2 R_1}{R_1R_2 + R_2R_3 + R_3R_1}$$

	Experimental value								Error (%)		
	V_1	V_2	R_1	R_2	R_3	I_1	I_2	I_3	I_1	I_2	I_3
1	2.92	3	8.5	10.2	47	0.027	0.0297	0.057	1.30	1.99	0.97
2	2.9	3.03	5.8	29.5	47	0.043	0.0125	0.056	0.93	3.41	0.79
3	2.89	3.04	3.5	47.3	47	0.050	0.0066	0.057	1.34	4.74	0.88
4	2.88	3.04	2.4	80.9	47	0.054	0.0035	0.058	1.40	2.93	0.64
5	2.88	3.04	1.2	100.5	47	0.057	0.0022	0.059	1.79	3.46	0.85

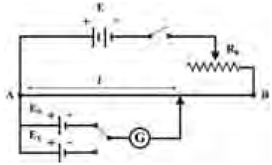
Wheatstone bridge: An unknown resistance is determined by balancing the current flow through resistive wire in Wheatstone bridge experiment.



$$\frac{R_1}{R_2} = \frac{R_3}{R_4}; \text{ then } R_X = \frac{L_1 \times R}{L_2}$$

R_X (Ω)	R (Ω)	L_1 (cm)	L_2 (cm)	R_X	Error (%)	
1.1	1.1	14	14.7	1.05	4.8	Average R_X 0.99Ω
1.1	2.3	9	20	1.04	5.9	
1.1	3.4	6.6	22.4	1.00	8.9	Average error 9.18%
1.1	5.7	4.2	24.8	0.97	12.2	
1.1	8.5	2.9	26.1	0.9	14.1	

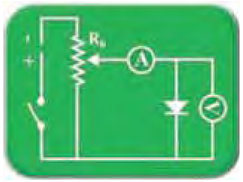
Sources of EMF: The electromotive force (emf) of the battery can be measured by a potentiometer by comparing the cell with another standard cell with a known emf value.

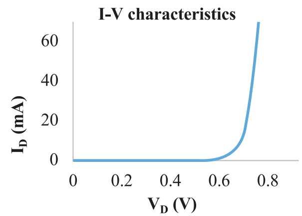


$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

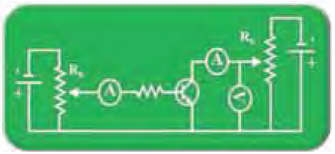
Power supply (V)	Test terminal (V)	E_S (V)	L_S (mm)	L_X(mm)	E_X (V)
2.92	1.377	1.0186	12.2	16.4	**1.37**
3.04	1.377	1.0186	14.9	20.2	**1.38**
3.39	1.377	1.0186	19.9	26.9	**1.38**
Average					**1.38**

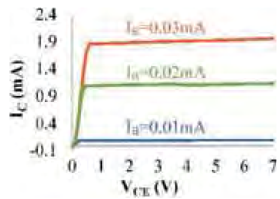
Current-Voltage characteristics of diode: Measurement of the current and voltage characteristic curve when silicon diode /1N4004/ is under forward bias.

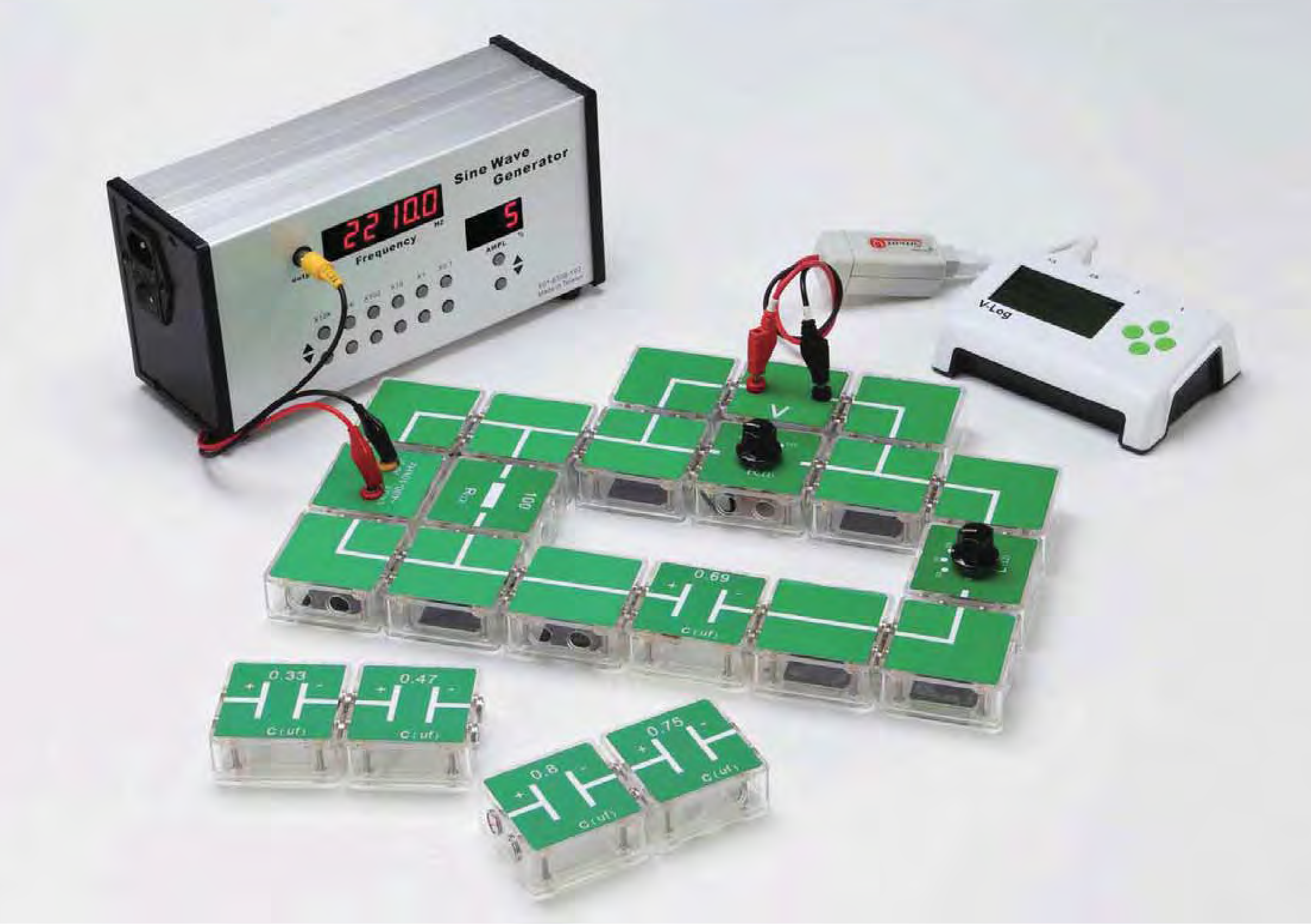




The I_C-V_{CE} characteristic curve of NPN transistor: $I_C - V_{CE}$ characteristic curve under constant I_B, where the NPN transistor is operating with forward bias between emitter and base and reverse bias between collector and base region.






Sine Wave Generator
2210.0
Frequency
5
AMPL
V-Log
V
100
0.69
C(uf)
0.33
C(uf)
0.47
C(uf)
0.8
C(uf)
0.75
C(uf)

F19 RC, LC and RLC Circuits

Experiments:

1. RC circuit charge and discharge
2. LC circuit resonance
3. RLC circuit resonance

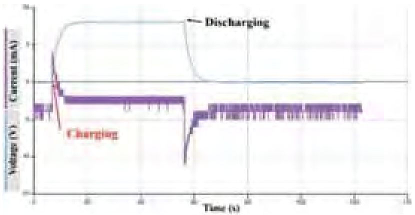
RC circuit charge and discharge: The time required for the capacitor to be charged to 63% of the full charge or to discharge to 36.8% of its fully charged state is called the time constant of the RC circuit and is calculated by:

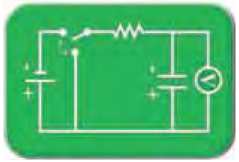
$$\tau = RC$$

Voltage across the capacitor during charge and discharge is:

$$\text{Charging: } V = V_s[1 - e^{\left(-\frac{t}{RC}\right)}]$$

$$\text{Discharging: } V = V_s e^{\left(-\frac{t}{RC}\right)}$$





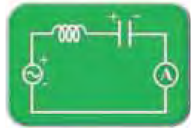
C (μF)	R (Ω)	Theo τ (s)	Voltage (V)	1T (V)	t_0	t_f	Exp τ (s)	Error %
Charge								
2200	1000	2.2	8.02	5.07	6.72	8.89	2.17	1.36
	120	0.26	8.09	5.11	1.9	2.18	0.28	6.06
	100	0.22	8.09	5.11	1.64	1.87	0.23	4.55
Discharge								
2200	1000	2.2	8.02	2.95	56.4	58.48	2.08	5.45
	120	0.26	8.09	2.98	17.22	17.48	0.26	1.52
	100	0.22	8.09	2.98	11.08	11.3	0.22	0.00

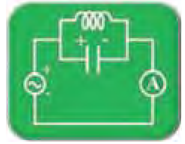
LC circuit resonance: In LC circuit, two reactance inductive X_L and capacitive X_C are equal in magnitude but reverse in sign at resonant frequency, thus the current is maximum.

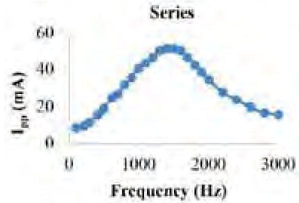
$$X_L = -X_C \quad \omega_0 = \frac{1}{\sqrt{LC}} \rightarrow f_0 = \frac{1}{2\pi\sqrt{LC}}$$

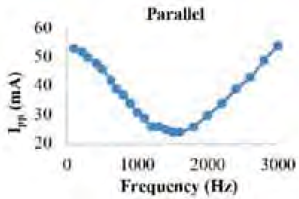
Theoretical resonant frequency for $C = 0.33\mu F, L = 33mH$ is

$$f_0 = 1525Hz$$



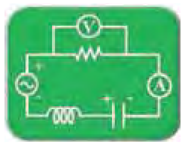






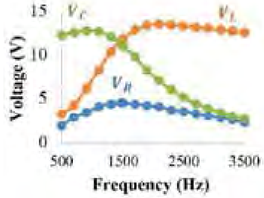
RLC circuit resonance: The resonant frequency of series and parallel RLC circuit is the same as the LC circuit without a resistor. The V_R is in phase with the I and V_L (leads) and V_C (lags) are out of phase with the I by 90°.

Series RLC

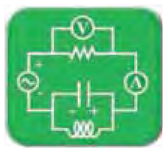


$f_0 = 1460\ Hz$
Bandwidth:
$BW = 1870Hz$
Quality factor:

$$Q = \frac{f_0}{B} = 0.781$$

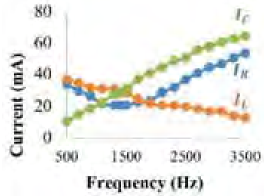


Parallel RLC



$f_0 = 1400Hz$
Bandwidth:
$BW = 1300Hz$
Quality factor:

$$Q = \frac{f_0}{B} = 1.077$$



N
S
V-Log
only for Induction
only for Generator

Experiments:

1. Determine earth magnetism by magnetic moment
2. Measure earth magnetism by tangent galvanometer
3. Magnetic field of coil
4. Current balance measurement
5. Direct current motor
6. Faraday's Law
7. Lenz's Law
8. Levitating ring
9. Generator
10. Transformer
11. Ferromagnetic hysteresis
12. Demo: Wireless signal transmission
13. Demo:Wireless electricity transmission
14. Demo: Energy conversion

Example:

Measure earth magnetism by tangent galvanometer:

If a compass is placed along the diameter of coil of the galvanometer with N number of turns and a radius, its needle will be perpendicular to the magnet. Therefore, the tangent earth magnetism B_G can be estimated:

$$B_G = \frac{\mu_0 N I}{2a \cdot tan\theta}$$

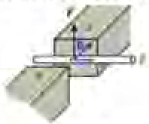
Here: $\mu_0 = 4\pi \times 10^{-7} H/m$ is the vacuum permittivity; and θ is a deflection angle of the compass.

Clockwise			Counter-clockwise		
$I\ (A)$	$\theta\ (°)$	$B_G\ (Gauss)$	$I\ (A)$	$\theta\ (°)$	$B_G\ (Gauss)$
0.55	55	**0.346**	0.37	45	**0.332**

The earth magnetism ranges between 0.25-0.65 *Gauss*

Current-Balance measurement: Lorentz Force

Magnetic field B acting on a current-carrying wire with N number of turns between two magnets can be measured with a digital balance as:



$$B = \frac{F}{INL} = \frac{0.0468kg \cdot 9.81\frac{m}{s^2}}{0.84A \cdot 20 \cdot 0.043m} = 0.063T = 635.5G$$

Here: I is the current;
L is the length of the wire; and
F is the force measured by a balance.

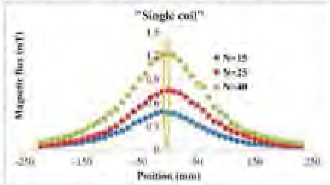
As the distance between two magnets decides the magnetic field, for different wire lengths, same magnetic field values were obtained.

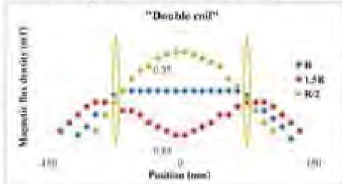
Distance between two magnets	$L = 4.3\ cm$			$L = 7.3\ cm$		
	$m\ (g)$	$I\ (A)$	$B\ (T)$	$m\ (g)$	$I\ (A)$	$B\ (T)$
0.045 m	4.68	0.84	**0.0635**	9.12	1.01	**0.0605**
0.0225 m	17.26	1.5	**0.1317**	29.4	1.45	**0.1365**

Magnetic field of single and double coils:

The magnetic flux can be visualized within the axial and radial axis around a current-carrying coil with different number of turns.

A uniform magnetic field can be obtained by adjusting the distance between two identical current-carrying coils to equal with coil radius R.





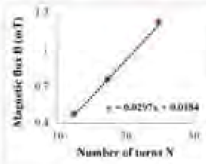
Vacuum permittivity

Current $I = 5A$

Radius a=0.105 m

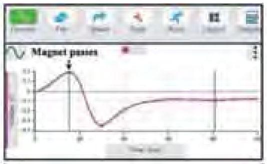
$slope = \frac{\mu_0 I}{2a} = 0.0297$

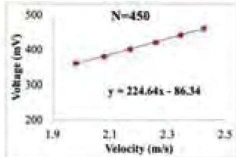
$\mu_{experimental}$	$1.217 \times 10^{-6} H/m$
$\mu_{theoretical} = 4\pi \times 10^{-7} H/m$	$1.256 \times 10^{-6} H/m$
Error of the experiment	**3 %**

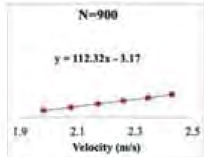


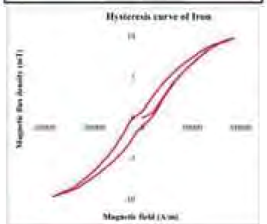
Faraday's Law:

When a magnet passes through a coil, it induces electromotive force ε in it and this can be measured as a resulting voltage. The voltage depends on the number of turns of the wire, as well as the velocity of the magnet.









Ferromagnetic hysteresis:

For ferromagnetic materials, the magnetic flux density is not proportional to the applied magnetic field and this relationship is represented in the form of a hysteresis loop.


TRANSMITTER

Experiments:

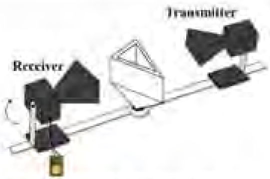
1. Standing wave
2. Reflection
3. Refraction
4. Polarization
5. Brewster's angle
6. Double slit interference
7. Michelson interferometer
8. Fabry-Perot interferometer
9. Lloyd's mirror
10. Bragg diffraction

Examples:

Refraction: The law of refraction is used to calculate the refraction index of salt using foam mold and microwave.

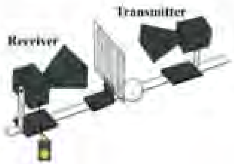
Snell's law: $n_1 sin\theta_1 = n_2 sin\theta_2$

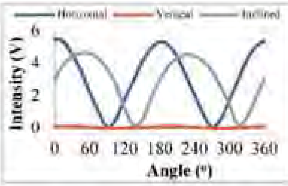
Refraction index of salt =1.54
Incident angle $\theta_1 = 30^o$
Reflected angle $\theta_2 = 52^o$
Refraction index of air $n_1 = 1$
Refraction index of salt $n_2 = 1.576$
Error = 2.34%



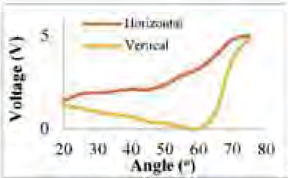
Polarization: Microwave is polarized with a metal grating polarizer rotated to three different configurations according to Malus' law.

$$E_{trans} = E_o sin\alpha$$



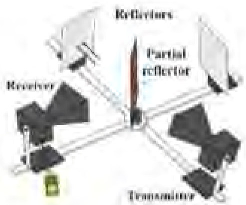


Brewster's angle: The Brewster's angle or the polarization angle is determined by measurement of horizontally and vertically polarized microwave reflected from partial reflector plate.



Michelson interferometer:

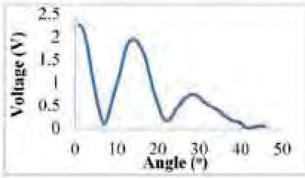
Determination of microwave wavelength by measurement of positions of antinodes.

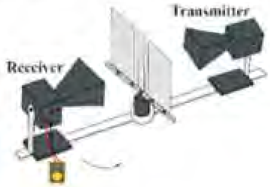


Initial position of reflector = 25 cm				
n	Position (cm)	Antinodes (mV)	λ/2 (cm)	λ (cm)
1	31.8	101	1.4	2.8
2	30.4	72	1.5	3
3	28.9	112	1.4	2.8
4	27.5	80	1.4	2.8
5	26.1	91	1.4	2.8
6	24.7	65	1.5	3
7	23.2	94	1.4	2.8
8	21.8	104	1.4	2.8
Average λ = 2.843 cm			Error = 0.25%	

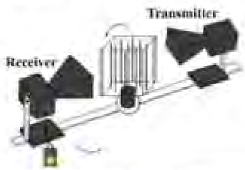
Double slit interference:

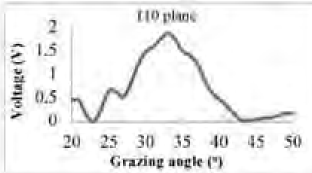
Double slit interference pattern is obtained using 2cm wide double slit metal plate.





Bragg diffraction: Lattice size and d-spacing of crystal lattice model can be found from first order diffraction by measuring microwave intensity at grazing angle θ.





	(110) plane					(100) plane				
n	θ	Sinθ	lattice size (cm)	d-spacing (cm)	Error (%)	θ	Sinθ	lattice size (cm)	d-spacing (cm)	Error (%)
1	33	0.54	3.70	2.62	3.5	24	0.41	3.50	3.50	10.4

Focal Length and Refractive Index

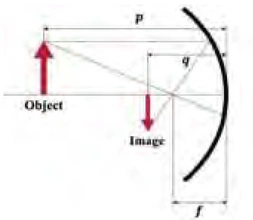
Experiments:

1. Focal length and magnification:
1.1. Concave and convex mirror
1.2. Concave and convex lens
2. Microscope featuring
3. Telescope featuring
3.1. Kepler telescope
3.2. Galileo telescope
4. Optical principles of the eye
4.1. Correction of myopia
4.2. Correction of hyperopia
5. Law of reflection: Plane mirror
6. Refractive index: Snell's Law
6.1. Acrylic
6.2. Liquids
7. Refractive index: Minimum deflection angle method

Example:

Focal length and magnification: "Concave mirror"

If an object with H_0 height is placed at distance p in front of the concave mirror with focal length f, a "real image" with H height will be formed at distance q.



Magnification, M is:

$$M_{theoretical} = \frac{q}{p} \quad \text{and} \quad M_{experimental} = \frac{H}{H_0}$$

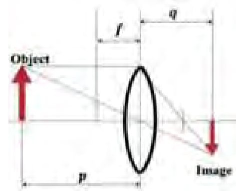
The focal length of the mirror: $f = +140\ mm$

Object distance p (mm)	Image distance q (mm)	Focal length f_0 (mm)	Height (mm) Object	Height (mm) Image	Magnification Theoretical $M = q/p$	Magnification Experimental $M=H/H_0$	Error (%)
345	235	146.625	10	8	0.73	0.8	8.8
375	245	148.185	10	7	0.65	0.7	7.1
405	235	148.710	10	6	0.58	0.6	3.3
435	225	148.295	10	6	0.51	0.6	15.0
465	215	147.022	10	5	0.46	0.5	8.0
Average focal length =147.76							

The experimental error of the focal length $= \frac{|f - f_0|}{f_0} \times 100\% = 5.5\%$

Focal length and magnification: "Convex lens"

If an object with H_0 height is placed at distance p (further than f) in front of the convex lens with focal length f, a "real" with H height will be formed at distance q behind the lens.



Focal length of the convex lens: $f_0 = +95\ mm$

Object distance p (mm)	Image distance q (mm)	Focal length f (mm)	Height (mm) Object	Height (mm) Image	Magnification Theoretical $M = q/p$	Magnification Experimental $M=H/H_0$	Error (%)
200	184	96.15	10	19	0.92	0.95	3.2
225	173	98.03	10	19	0.77	0.84	8.3
250	169	101.01	10	19	0.68	0.68	0.0
275	150	97.09	10	19	0.55	0.58	5.2
300	145	98.04	10	19	0.48	0.53	9.4
Average focal length, f = 98.13							

The experimental error of the focal length$= \frac{|f - f_0|}{f_0} \times 100\% = 3.3\%$

Refractive index: Snell's Law

When light enters with θ_i incident angle from one medium with n_1 refractive index to another with n_2, it will refract to angle θ_r :

$$n_i sin\theta_i = n_r sin\theta_r$$

Refractive index: acrylic n =1.4889
water n =1.333

Material	Acrylic					Liquid: Water		
Times	Incident angle θ_i (°)	Incident angle $sin\theta_i$	Refraction angle θ_r (°)	Refraction angle $sin\theta_r$	Experimental n	Refraction angle θ_r (°)	Refraction angle $sin\theta_r$	Experimental n
1	10	0.17	6.6	0.11	1.4795	8	0.14	1.22
2	20	0.34	12	0.21	1.6358	15	0.26	1.31
3	30	0.5	17	0.29	1.7107	23	0.39	1.28
Average n	1.60					1.27		
Error (%)	7.4					4.7		

Experiments:

1. Single slit diffraction
1.1. Determination of wavelength
1.2. Effect of the slit width
1.3. Effect of the screen distance
2. Double slit interference
2.1. Determination of wavelength
2.2. Effect of the slit width and separation
3. Multiple slit interference
3.1. Determination of wavelength
3.2. Observation on number of slits
4. Diffraction grating
4.1. Determination of wavelength
4.2. Observation on number of slits
5. Polarization of light

Example

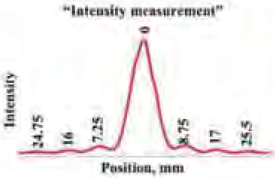
Single slit diffraction: "Determination of wavelength"

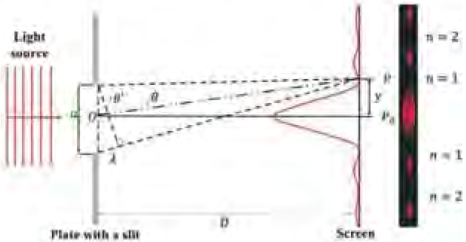
According to the Huygens's Principle, the wavelength can be estimated from the single slit diffraction pattern as:

$\lambda = \frac{ya}{nD}$ when n=1, 2, 3 there will be dark regions

Here: y is the position of dark fringes;
a is the slit width; and
D is the screen distance.

Experimental result:

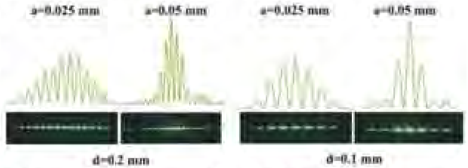




"RED LASER"; Slit a = 0.11 mm; Distance between screen and slit D = 1390 mm							
Dark fringes	Position, y (mm)			λ_{exp} (nm)	Average	$\lambda_{theor.}$ (nm)	Error (%)
	Right	Left	Average				
1st	8.75	7.25	8.00	633	649.6	650	0.05
2nd	17.00	16.00	16.50	653			
3rd	25.50	24.75	25.13	663			
4th	8.75	7.25	8.00	633			

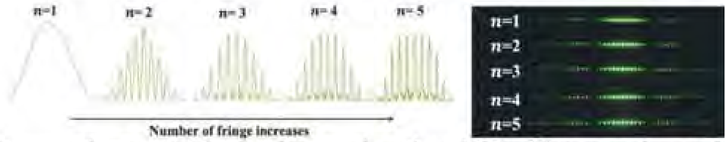
Double slit interference: "Effect of the slit width and separation"

The brightness of the visual patterns on the screen can be displayed as graphs by a measurement for investigating the effect of slit a and separation d:



Multiple slit interference: "Observation on number of slits"

As the number of slits increases, the main group of bright fringes will become sharp and intense whereas, the minor bright fringes weaken and become fainter.



Diffraction grating: "Observation on number of slits"

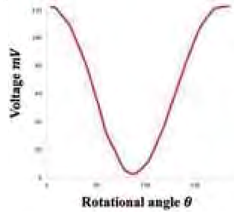
If the separation between each slit is very small, the light will superpose and interfere with each other, form extremely narrow bright interference fringes within the diffraction envelope.

Polarization of light:

According to the Malu's Law, the intensity of the irradiance or the transmitted light I_T depends on the cosine of mutual angle θ between analyzer and polarizer.

$$I_T = I_0 \cos^2 \theta$$

The maximum transmission is at 0° and 180° and maximum transmission is at 90°; and this cosine nature of the transmittance can be visualized experimentally as follows:



Experiments:

1. Newton's ring experiment
2. Lloyd's mirror
3. Michelson interference

Newton's ring experiment:

Interference rings formed by light incident on the thin film of air between a convex lens and a flat lens is used to measure the radius of curvature precisely.

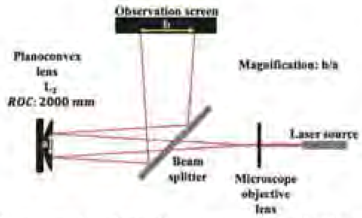
Intensity peaks measured by the photodetector

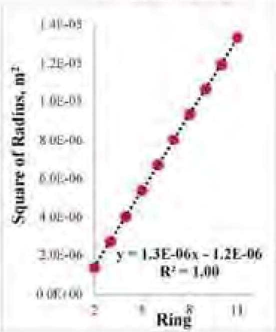
Corresponding rings

$$R = \frac{(r_{m+n}^2 - r_m^2)}{n \cdot M^2 \cdot \lambda}$$

Here:

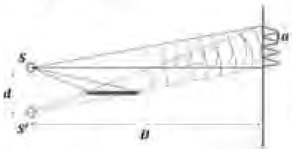
r_m is the radius of m^{th} ring,
r_{m+n} is the radius of $(m+n)^{th}$ ring,
M is the magnification, and
λ is the wavelength of the laser source.





Measured radius of curvature $R = 2.038\ m$
Actual radius of curvature $R = 2.000\ m$
The error of the experiment: 3.8%

Lloyd's mirror:

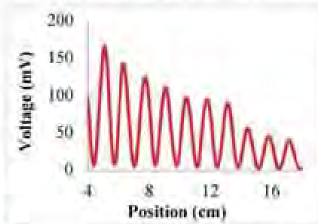


If a light from a monochromatic slit source reflects from a glass surface at a grazing angle at B distance, the reflected light interferes with the direct light from the source, forming interference fringes. The wavelength can be determined with an imaging lens with f focal length at b distance by using the resulting pattern.

$$\lambda = \frac{afB}{b^2}$$

a is the distance between fringes,
g is the laser to imaging lens distance,
L is the laser to screen distance.

Focal length of imaging lens $f = +95\ mm$

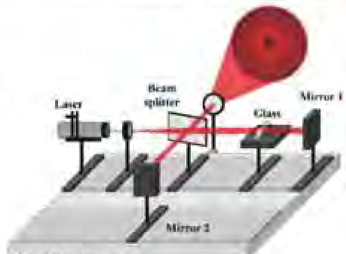


	Maxima		Minima	
	Position (mm)	d (mm)	Position (mm)	d (mm)
1	5.1	1.2	5.7	1.35
2	6.3	1.45	7.05	1.35
3	7.75	1.35	8.4	1.4
4	9.1	1.35	9.8	1.35
5	10.45	1.35	11.15	1.3
6	11.8	1.35	12.45	1.4
7	13.15	1.3	13.85	1.35
8	14.45	1.4	15.2	1.3
9	15.85	1.3	16.5	1.4
10	17.15	-	17.9	-
Average= 1.35				

Measured wavelength $\lambda = 658nm$
Actual wavelength $\lambda = 650\ nm$
The error of the experiment: 1.3%

Michelson interferometer:

It uses a method to split the single beam to produce double light beam interference. Refractive index of glass n can be determined by change in optical path length as follows:



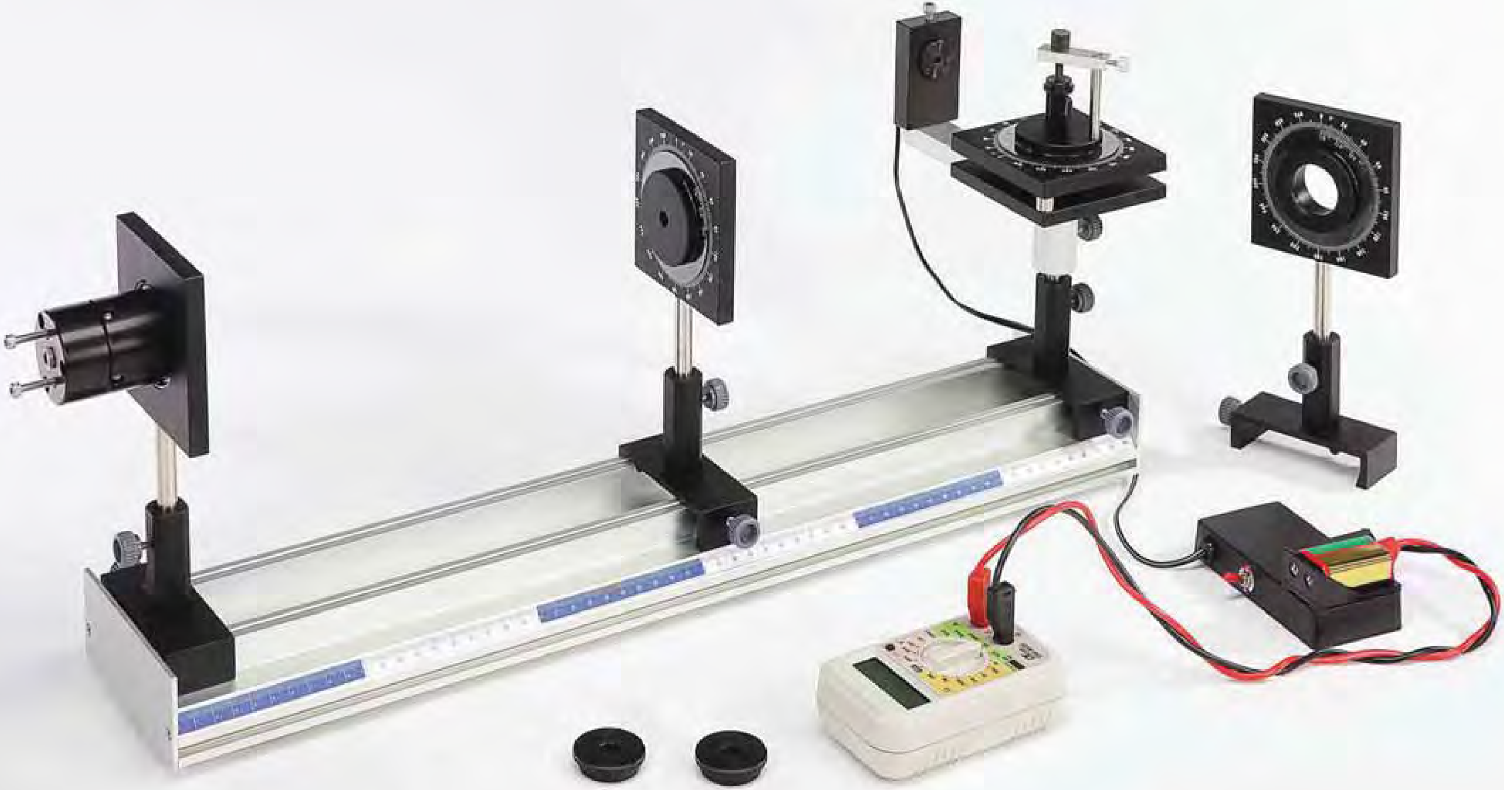
$$n = \frac{(1-cos\theta)(2d-N\lambda)+N^2\lambda^2}{2d(1-cos\theta)-N\lambda}$$

θ is the incident angle,
d is the thickness of the glass slide, and
λ is the wavelength of the laser source.

Object to be tested: Glass slide

Laser source wavelength: $\lambda = 650\ nm$
Glass thickness: $d = 1\ mm$
Theoretical n =1.517
The error of the experimental: 0.25%

Angle θ (°)	Fringe count N	Refractive index n
11	20	1.537
15.5	40	[illegible]
[illegible]	[illegible]	[illegible]
34.5	200	1.502
Average n		1.521

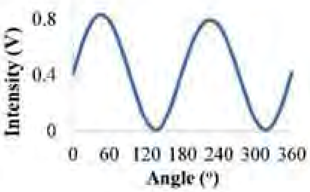


Experiments:

1. Malus law
2. Half and quarter wave plate
3. Brewster's angle

Malus law:

When completely plane polarized light is incident on the analyzer, the intensity I_T of the light transmitted by the analyzer is directly proportional to the square of the cosine of angle between the polarization axis of the analyzer and the polarization axis of the polarized light, θ.



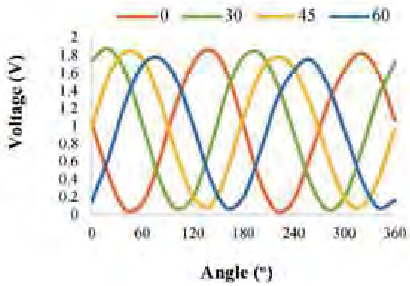
$$I_T = I_0 \cos^2 \theta$$

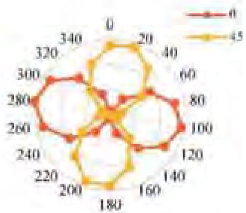
Half and quarter wave plate:

A Waveplate resolves light wave into two orthogonal linear polarization components by producing a phase shift between them.

Half wave plate

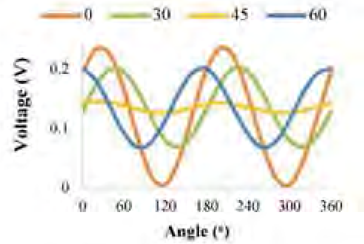
Linear polarized light goes through half wave plates, a phase difference of $\lambda/2$ is produced

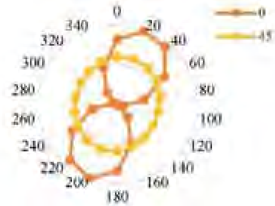




Quarter wave plate

Linear polarized light is transformed into circularly polarized light and the other way around by introducing a λ/4 (quarter) wave plate with its axes oriented at 45°.



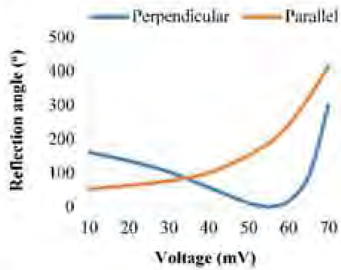


Brewster's angle:

When light is reflected from the surface of higher refractive index, the reflected ray's intensity changes with change in the incident angle (θ_I).

At Brewster's angle (θ_B) only perpendicular vibrations of electric field vectors are reflected whereas parallel vibrations are restricted or polarized. Due to polarization by reflection intensity of light is at minimum.

Reflection angle (°)	Intensity (*mV*)	
	Perpendicular	Parallel
10	162.7	55.2
20	137.4	66.1
30	105.4	79
40	60.2	102.7
50	13	153.3
54	3.8	182.2
55.4	2.6	196
55.8	2.8	197.7
58	8.1	221
60	20	245
65	94	324
70	301	417



by Laser
Laser
A
V

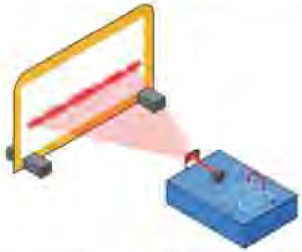
Experiments:

1. Wavelength of semiconductor laser
2. Threshold voltage of semiconductor laser
3. Determination of Planck's constant

Wavelength of semiconductor laser:

The wavelength of the diode laser is determined by the single slit diffraction experiment.

By measuring the distance ($2y_n$) between central bright region to dark regions of the interference pattern, we can calculate the wavelength of laser.

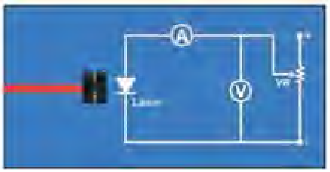


The wavelength is found by:

$$\lambda = \frac{dy_n}{nL} \;; n = 1,2,3,\dots$$

Distance between laser and the board $L = 1265mm$						
Slit width (mm)	n	$2y_n$ (mm)	y_n (mm)	λ (nm)	Average λ (nm)	Error (%)
$d = 0.11$	1	15.45	7.73	671.74	665.30	2.35
	2	29.00	14.50	627.95		
	3	45.35	22.68	654.66		
	4	60.70	30.35	657.19		
	5	78.00	39.00	675.59		
	6	95.00	47.50	685.70		
	7	110.60	55.30	684.25		

Threshold voltage of semiconductor laser:

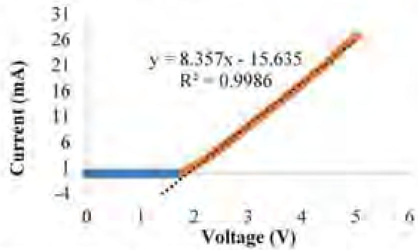


The threshold voltage (V_{th}) of laser diode is calculated from measurement of its $I-V$ curve.

Once the voltage passes V_{th}, the stimulated emission causes a sudden rise in the slope of the curve.

Linear regression equation:

$$y = 8.357x - 15.635$$



The threshold voltage:

$$8.357V_{th} - 15.635 = 0$$

$$V_{th} = \frac{15.635}{8.357} = 1.871\,V$$

Determine the Planck's constant:

When the applied voltage provides sufficient energy (eV_{th}) for the electrons they can jump to the higher energy state and falls back to lower energy state emitting photons as a result. The energy of the emitted photon is:

$$hf = eV_{th}$$

By using the wavelength of the emitted photons, Planck's constant can be calculated by:

$$h = \frac{eV_{th}}{f} = \frac{eV_{th}\lambda}{c}$$

Wavelength (λ) : $665.3\ nm$

Threshold voltage (V_{th}): $1.871V$

The Planck's constant: $h = 6.62 \times 10^{-34} \frac{m^2 kg}{s}$

Experimental Planck's constant: $h = 6.65 \times 10^{-34} \frac{m^2 kg}{s}$

The error of the experiment= $\frac{h_{experimental} - h}{h} = 0.3\%$

Experiments:

1. Continuous spectrum of incandescent lamp
2. Absorption spectrum of color plates
3. Emission spectrum of Fluorescent lamp
4. Observation of solar absorption spectrum

Continuous spectrum of incandescent lamp:

Incandescent lamp emits light from hot metal filament with continuous spectrum which can be observed through diffraction grating.

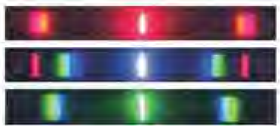
$$\lambda = \frac{d \times l}{\sqrt{s^2 + l^2}}$$

Grating width: d
Distance from grating to light source: s
Distance from spectra to light source: l

Grating width, d = 500 lines/mm = 0.002mm Distance from grating to light source, s = 46 cm							
	Left l (cm)	Experimental λ (nm)	Theoretical λ	Right l (cm)	Experimental λ (nm)	Average λ (nm)	Average error %
Violet	9.5	402.8	400	9.5	402.8	402.8	0.71
Blue	10.6	447.3	450	10.6	447.3	447.3	0.61
Cyan	11.5	483.1	500	11.6	487.0	485.1	2.99
Green	12.9	537.9	550	13	541.7	539.8	1.85
Yellow	13.7	568.6	580	13.9	576.2	572.4	1.31
Orange	14.7	606.4	600	14.8	610.1	608.3	1.38
Red	15.6	639.8	650	15.7	643.5	641.7	1.28

Absorption spectrum of color plates:

Measurement of the wavelength range of continuous spectrum and light filtration of the color filter plates:

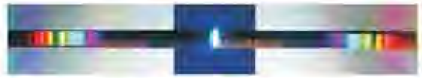


Wavelength range of continuous spectrum after the light filtration:

Filter	Left side				Right side				Average λ (nm)	
	Upper limit		Lower limit		Upper limit		Lower limit		Upper limit	Lower limit
	l (cm)	λ (nm)	l (cm)	λ (nm)	l (cm)	λ (nm)	l (cm)	λ (nm)		
Red	14	580.0	19.2	767.5	14.3	591.4	19.2	767.5	585.7	767.5
Blue	9.5	402.8	13.9	576.2	9.7	411.0	14.2	587.6	406.9	581.9
	14.5	598.9	15.6	639.8	14.8	610.1	15.7	643.5	604.5	641.7
	16.2	661.8	19.2	767.5	16.5	672.7	19.3	770.9	667.2	769.2
Green	10.9	459.3	14.7	606.4	11	463.2	14.8	610.1	461.2	608.3

Emission spectrum of Fluorescent lamp:

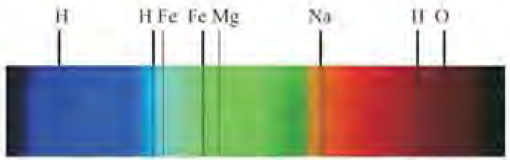
Observation of discrete emission spectra of fluorescent lamp containing mercury vapor. The wavelengths of these emission lines are measured and compared with the theoretical emission spectrum of mercury vapor.



Grating width, d = 500 lines/mm, Distance, s = 46.2 cm							
	Left l (cm)	Exp λ (nm)	Theo λ	Right l (cm)	Exp λ (nm)	Average λ	Average error %
Blue	10.3	435.2	435.8	10.2	431.2	433.2	0.60
Green	13.1	545.6	546.1	13	541.7	543.7	0.45
Yellow*	14.1	583.8	579.1	13.9	576.2	580.0	0.52
Red	15.1	621.3	623.4	14.9	613.9	621.3	0.34

Observation of solar absorption spectrum:

Observe Fraunhofer lines in solar absorption spectra using diffraction grating spectroscope. Some of the distinct absorption lines are identified.




V-Log

Experiments:

1. Stefan-Boltzmann Law
2. Blackbody spectrum
3. Atomic spectrum (Optional)

Example

Stefan-Boltzmann Law: "Temperature of the filament"

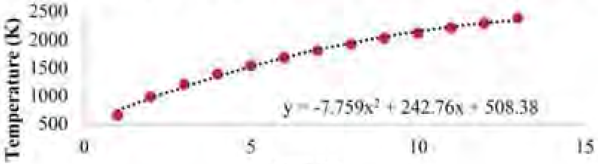
The temperature of tungsten filament lamp can be determined by measuring its resistance by measuring its current and voltage when the lamp is connected to power.

$$T = \frac{R - R_0}{\alpha R_0} + T_{room}$$

Here: T is the temperature,
R is resistance at temperature T
T_{room} is room temperature,
R_0 resistance at T_{room}, and
α is the temperature coefficient of resistivity for the filament.

at T_{room}=28°C

Resistance of the light bulb without current flowing in it, R_0=0.7 Ω



$$T = \frac{1.9\Omega - 0.7\Omega}{0.0045\frac{1}{°C} \times 0.7\Omega} + 28°C = 666.9K$$ and so on

Blackbody spectrum

The wavelength corresponding to the peak intensity of radiation is inversely proportional with temperature:

$$\lambda_{max} = \frac{hc}{(4.965)k_B T} = \frac{2.898 \times 10^{-3} m \cdot K}{T}$$

The blackbody radiation curve for different temperature will peak at different wavelengths, and this relationship between the temperature and the wavelength of maximum intensity is known as *Wein displacement Law.*

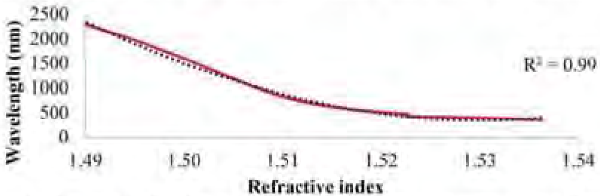
To plot this relationship, firstly, the corresponding refractive index of the prism at different angle can be estimated as follows:

$$n = \sqrt{\left(\frac{2}{\sqrt{3}}\sin\theta + \frac{1}{2}\right)^2 + \frac{3}{4}}$$

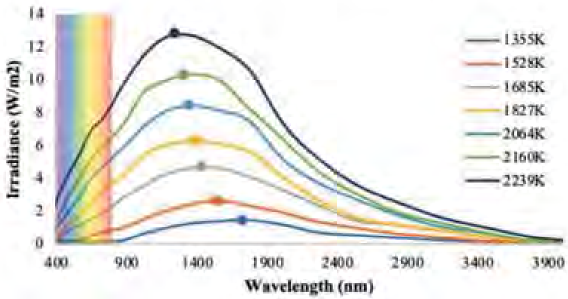
Here: θ is the measured angle when the incident angle is 60°.

Secondly, the wavelength can be found from the calculated refractive index by the equation obtained from the reference data provided by the manufacturer as follows:

$$\lambda = 2{,}883{,}853.53x^3 - 11{,}878{,}002.18x^2 + 16{,}093{,}941.55x - 7{,}146{,}901.01$$



Ultimately, the applied voltage can be converted into temperatures from the first experiment.



Wired SmartQ sensors

No charging needed   Requires Datalogger

With over 50 sensors to choose from, there's a sensor available for almost all scientific experiments.

Wireless Bluetooth sensors

Single charge can last up to a year   Designed for phones

In addition to the convenient wireless sensing, it also functions as a datalogger in their own by using both Bluetooth or USB connectivity. Currently 18 types of sensors are available, and others will be launched soon.

Sensors for Demo & Experiments in Physics:

Temperature sensor
Current sensor
Voltage sensor
Gas pressure sensor
Light sensor
Infrared sensor
Force sensor
Magnetic field sensor
Light gate sensor
Rotary motion sensor
Accelerometer
Sound sensor
Motion sensor
Geiger Muller sensor

V-log Datalogger

- ✓ LCD screen
- ✓ Features 4 **SmartQ** sensor inputs
- ✓ Log data from multiple sensors at the same time
- ✓ Fastest speed: 50 000 samples per second
- ✓ Digital timing accuracy: 4 microseconds

Simultaneous and accessible

EasySense2 Software

Data capturing, displaying and analyzing cross-platform software

- ❖ Free to download
- ❖ 15 languages to choose
- ❖ Captures data from multiple devices at the same
- ❖ Line graphs, gauges, numbers and bar charts are available
- ❖ Performs mathematical operations on the recorded data
- ❖ Logging modes: Continuous recording, Snapshot and Timing
- ❖ Export in CSV format
- ❖ Support for printing

D01 DEMONSTRATION ON ELECTROMAGNETIC INDUCTION

Switching lights, energetically jumping rings and swirling discs are the eye-catchers to bring excitement into the classroom. With this experimental model proposed, student's learning motivation is believed to be inspired remarkably not only for electromagnetism but also Physics, in general. This portable equipment is designed to display essential demonstrations based on the fundamental principle of electromagnetism. By combining Faraday and Lenz's Laws, this set easily induces an eddy current, which not only offers an effective way for students to understand the basic theory of electricity - magnetism but also helps to visualize and sense the complicated concepts.

Eddy current brake

Contactless generator

DC and AC

Contactless electricity transfer

Transformer

Thomson coil

Time warp tube

CIDISK (Thailand) Co., Ltd.
119/241 Soi Khubon 27 Yaek 11, Tharaeng, Bangkhen, Bangkok 10220
Tel: 092-4646-525   Line ID: cidiskthailand
Email: sales@cidiskthailand.com, cidiskthailand@gmail.com

Special thanks to Ms. Otgon-Ujin and Ms.Tuul from Mongolia,
who helped with development of the experiment and
wrote the manual for the sets.

SF Scientific Co., Ltd.
No.72-1, Jiankang 2nd street, Anping district, Tainan city, 70846 Taiwan.
Tel: +886-62953403 Fax: +886-62957961
E-mail: a9251255@gmail.com
Skype: andrewwang111
www.sfscientific.com