

ADVANCED HIGHER PHYSICS INVESTIGATION

Student Handbook

Heriot-Watt University
Department of Physics
School of Engineering and Physical Sciences
2009/10

Disclaimer

Heriot-Watt University EPS-Physics are continuously reviewing the format, and experiments that are on offer for the Advanced Higher Physics practical investigation. As this is an ongoing process, the current document is updated regularly. Consequently please check that you have the most recent version. Plus, any feedback is appreciated from both teachers and pupils.

Advanced Higher Physics Investigation

The Scottish Qualifications Agency (SQA) requires that all Advanced Higher (AH) physics pupils conduct a practical physics investigation. The investigation aims to develop practical and experimental skills through a practical project plus provide opportunity for both self-motivation and organisation skills. A collaboration between the Department of Physics in the School of Engineering and Physical Sciences (EPS) at Heriot-Watt University and the Institute of Physics (IOP) provides an experimental laboratory for advanced higher pupils to fulfil part of the physics investigation.

Day trips to Heriot-Watt will allow a series of experiments suitable for the investigation to be undertaken. Teachers and pupils will be informed before their visit of the experiments that are available and all parties are expected to prepare in advance for any chosen experiment. This is considered part of the planning stage of the project and is vital for the successful outcome of the investigation. During the time at Heriot-Watt expert advice and assistance will be available through demonstrators who will help with the investigation and experiment. This is an opportunity for interaction with research physicists who study and work in a university environment.

Notes on keeping a record book

As well as developing investigative skills, students are expected to learn how to organize their experimental study and how to maintain a good laboratory record. A successful outcome will be invaluable for those continuing to study science or engineering. Accurate record keeping and logical analysis are the basis for effective scientific study. The SQA requires students taking AH physics to plan their investigation before they perform experiments, so that the aims and objectives are well established. In order to prepare themselves students must record their plans in a "daybook" during this initial phase, and then they should continue to record the experimental investigation in the same book. The investigation thus begins before any laboratory work. These written, dated details form part of the AH assessment, and a similar requirement is normal for university project work.

Data from the practical investigation are to be documented in the daybook: these will include not only the experimental details, but also the results, calculations, and conclusions. Readings from equipment should be tabulated before fully labelled graphs are produced from them. Experimental errors must also be noted at the same time. Measurements that do not include tolerances and results that do not include uncertainties, as indications of their reliability, are not acceptable in science or engineering. Readings and results that do not include units are also unacceptable. Remember that production of a final report on any extended investigation will rely on clear record keeping.

Often during an investigation, mistakes may be made in taking readings or in calculating results, or a line of enquiry may be rejected. These “errors” should not be erased from the record, but should be crossed out neatly and the reason noted: sometimes these apparent mistakes turn out to be significant and have to be reconsidered in the light of later results, thus they must remain legible.

If software packages are used to produce graphs or drawings then their outcomes should be included in the daybook, with any printed pages attached securely to the book. Similarly, any written sources or webpages that are consulted should be noted at the time in the daybook, so they may be found later if needed. This also avoids uncertainty between originality and referenced work, so that there is no unintended copying (plagiarism). Any contributions by others should be noted in the book for the same reason.

A clear and complete record of the whole investigation will smooth the progress of writing the final report!

Finally, remember that whatever format is required for a final report, it will generally be a logical sequence that may include the following aspects.

- introduction (underlying science and context of the investigation);
- experimental method (with sufficient detail to enable another student to repeat the experiment);
- results with experimental errors;
- any calculations with appropriate graphs;
- discussion of the significance of the results;
- conclusion
- references and bibliography
- acknowledgments to assistants

Treatment of Errors

Errors, or uncertainties, are an inherent feature of all scientific work and it is important to keep track of all errors in an experiment. An experimental error is not a mistake, nor is it an indication of a failed or poorly performed experiment, it is scientific fact and must be given appropriate consideration. This brief section is intended as a rough guide to the concept of errors: a full description of analysis is outwith the scope of this handbook and is discussed in the course material for advanced higher. It is advised that you discuss with a lab demonstrator/teacher if you are unsure about the errors of a particular experiment.

There are three types of errors, systematic, random (statistical) and human (personal).

A *systematic error* is a non random error (i.e. one that is always the same, no matter how many times the experiment is repeated) and is normally due to the experimental equipment. An example of a systematic error is a poorly calibrated ohmmeter that measures 10 Ohms when applied to a short-circuit, thereby resulting in all further readings being 10 Ohms higher than they should be. Most systematic errors can be identified via data from a known calibrated source and therefore compensated for when analysing the experimental data.

A *random error* is the most common form of error and arises from unpredictable changes in experimental conditions. For example, an ohmmeter can be said to be accurate to within 5%, meaning that all measured values carry an error of $\pm 5\%$. Random errors can often be reduced by repeating the same measurement many times, and then describing the distribution of error values. It is important to keep track of all random errors so that they can be suitably combined when analysing your data.

Human error is not a mistake made by the scientist, it is an error originating from a decision or interpretation that the scientist must make when collecting the data. For example, in an experiment where a scientist must decide when two light sources are at the same intensity by only using his/her eyes there is a level of interpretation from the scientist that must be considered. This gives rise to an error. Such errors can often be quantified by repeating the experiment many times to produce a range of readings, and therefore a mean and standard deviation.

Errors must be correctly included in your final readings by means of percentage errors, standard deviation, plus or minus values or error bars on graphs. Appropriate statistical analyses and combination of errors must also be included. Comments on the origins of your errors and how they relate to your experiment are also required. Remember that a scientific result quoted without an appropriate error is meaningless and is not accepted in scientific studies.

Schools Lab Experiments

The following is a list of experiments currently on offer in the advanced higher laboratory. Students should select experiments in advance and familiarize themselves with the concepts for the experiment, outlined below, before coming to the University.

Contents

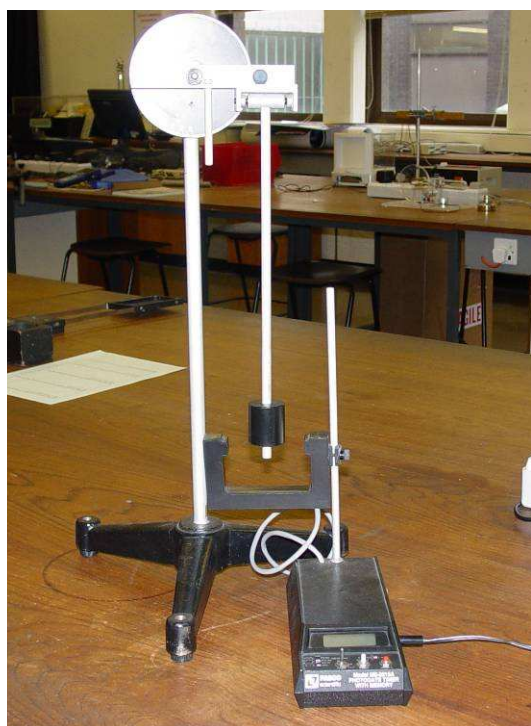
Period and length of a simple pendulum - Measurement of g	6
The Compound Pendulum.....	7
Determination of the gravitational constant G	10
Angular acceleration and torque	12
Mass on a spiral spring.....	13
Hooke's Law	14
Coulomb's Law	15
Force on a current-carrying conductor	17
Current and frequency in an inductive circuit	18
Self-inductance of a coil.....	19
Thin Lenses	20
Reflection and refraction	21
Optical polarization & Brewster's angle.....	22
Polarization – Malus' Law	24
Wavelength of red light using a helium-neon laser	25
Determining the track spacing on a CD using a laser	26
Speed of Light	27
Measurement of Refractive Index of Air Using Michelson Interferometer	28
Ideal Gas Law	30
Determination of Absolute Zero	31
Viscosity	32
Experimental Aerodynamics.....	33
Resonance Tube	35
Speed of Sound	37

Period and length of a simple pendulum - measurement of g

A simple rigid pendulum with variable bob is used to determine g.

Outline: By adjusting the position of the pendulum bob along the aluminium rod and using the timer to record the time for one oscillation, the dependence of period on length can be investigated. From this data, the gravitational field strength can be determined.
Further work: Pendulum motion can be set at an angle to the vertical, allowing determination of g equivalent to those on other planets.

Concepts: Centre of mass
Period of simple pendulum



Required equations:

$$T = 2\pi \sqrt{\frac{l}{g}}$$

Where T = period of pendulum
 l = length of pendulum
 g = gravitational field strength

The centre of mass of a system is

given by $l_{corr} = \frac{\sum m_i l_i}{\sum m_i}$. The pendulum

used in this experiment consists of an aluminium rod of length 30.0 cm and mass 26.0 g, and a pendulum bob of mass 200 g. So the centre of mass of the pendulum bob and aluminium rod is given by

$$l_{corr} = \frac{(26.0 \times 15.0) + (200 \times l)}{226}.$$

Equipment: Variable 'g' pendulum
Photo-gate timer
Metre stick

Notes: Position the photo-gate so that the pendulum bob does not hit the gate as it passes through.
When the timer is set to 'PEND', it will record the time for one complete oscillation of the pendulum.

Compound Pendulum

A compound pendulum is used to determine g .

Outline: Any rigid body suitably suspended at a point oscillates under gravity just like a simple pendulum. A body such as this is called a compound pendulum. The compound pendulum has holes drilled at regular intervals, by measuring the period of oscillation at different points of suspension, values for g (gravitational field strength) and k (radius of gyration) can be determined.

Concepts: Compound pendulum
Simple harmonic motion.



Equipment: Compound pendulum
Support
Stop-watch
Metre stick

For further notes and Example Experiment please see next page.

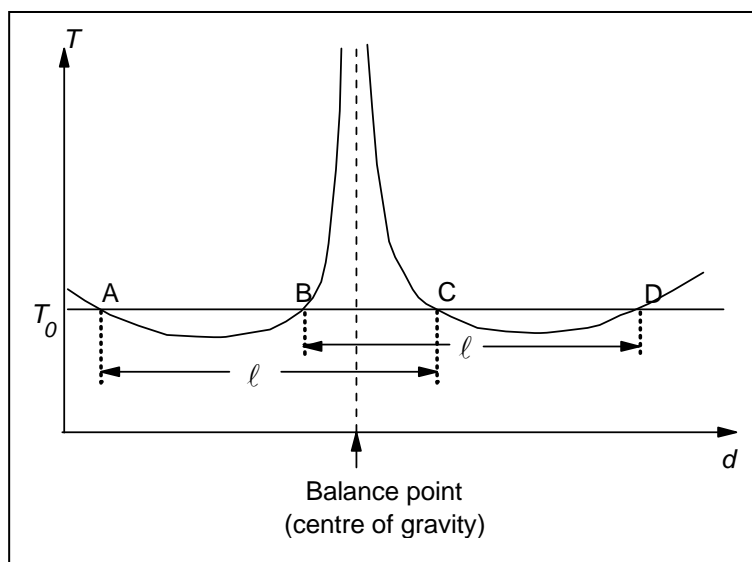
The compound pendulum is more complicated than the simple pendulum. The mass of a pendulum bob is distributed in space, and the string has been replaced by rigid material. The mathematical description now uses the rotational equivalent of Newton's laws for rigid bodies, with velocity replaced by angular velocity, torque replacing force, and moment of inertia replacing mass.

Example Experiment

The compound pendulum has holes drilled at regular intervals. Hang it from the knife edge support as illustrated in the above figure and level the support so that it swings in one plane (i.e. minimise any wobbling).

Measure the time taken for the pendulum to make a number of complete oscillations of small amplitude to calculate the period of oscillation. Repeat the experiment varying the point of suspension each time.

Graph the oscillation period versus the distance between one end of the pendulum and each point of suspension. A curve similar to the one shown below should be obtained.



Analysis Outline

The equation for the period of oscillation of the compound pendulum is :

$$T = 2\pi \left[\frac{k^2 + h^2}{gh} \right]^{1/2}$$

Defined from simple harmonic motion and the moment of inertia. k is a constant known as the *radius of gyration* which depends on the mass distribution of the body and the plane in which it oscillates. The term h describes the distance between the compound pendulum centre of gravity and the pivot point.

By equating the above equation with that of a standard pendulum we see that:

$$\ell = \frac{k^2 + h^2}{h}$$

By rearranging to a standard quadratic expression and solving for h we see that:

$$h_1 = \frac{\ell + \sqrt{\ell^2 - 4k^2}}{2} \quad \text{and} \quad h_2 = \frac{\ell - \sqrt{\ell^2 - 4k^2}}{2}$$

The above expressions can be used to extract a value of the acceleration due to gravity, g from the measured data. A horizontal line corresponding to a chosen value of the period T_0 will cut the graph in four points (A, B, C and D in). Since h_1 and h_2 are the distances of the suspension points from the centre of gravity for any chosen period, their sum is obtained by using unsymmetrical positions that are on opposite sides of the centre of gravity. Thus ℓ , the length of the simple equivalent pendulum is the distance from A to C or from B to D. The value of g is obtained by substituting corresponding values of ℓ and T_0 in the equation for a standard pendulum.

Determination of the gravitational constant G

Cavendish's experiment is used to determine a value for the gravitational constant, G .

Outline: Fixed large masses displace smaller masses that form part of a sensitive torsion pendulum. By changing the position of the large masses and measuring the oscillation of the smaller masses, using a laser and mounted scale, a value for the gravitational constant, G , can be determined.

Concepts: Gravitational constant
Cavendish experiment

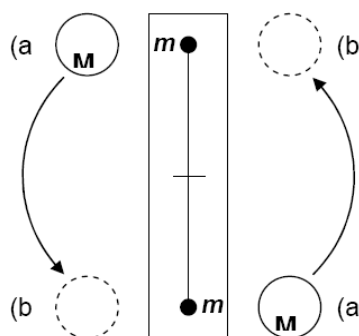


Equipment: Cavendish apparatus
Mounted scale
Laser pointer
Stop-watch
Metre stick

Notes: The apparatus used in this experiment is extremely delicate and sensitive. Do not touch anything until you are sure you know how to carry out the experiment. Please read Further Notes on next page. When moving the large masses do not knock the case containing the small masses.
DO NOT look directly at the laser beam.

Further Notes on Gravitational experiment:

This method is similar to that used by Cavendish.



When the smaller spheres are moved from position (a) to (b), a damped oscillation in the torsion pendulum occurs as it moves to a new equilibrium position. The period of oscillation, for this apparatus, is approximately 10 minutes. By noting the initial equilibrium position of the laser point reflected off the pendulum, and measuring its displacement every 30 seconds over a period of an hour, the damped oscillation can be plotted.

The value of the gravitational constant G is calculated by using the expression

$$G = \left[\frac{\pi^2 a^2 d}{ML} \right] \left[\frac{S}{\tau^2} \right]$$

In this expression:

a = average distance from centre of large sphere to centre of small sphere

d = half distance between the small spheres = 5.00 cm

L = distance from mirror to spot

M = mean mass of large spheres = 1.46 kg

S = difference of scale readings of the equilibrium positions of the spot for positions (a) and (b)

τ = period of oscillation of the torsion pendulum

The correction factor needed to take account of the attraction between each large sphere and the *further* of the two small spheres is

$$\left[1 - \left(\frac{1}{1 + \left(\frac{2d}{a} \right)^2} \right)^{3/2} \right]^{-1}$$

For the apparatus used, this correction factor becomes 1.07.

Multiply the value of G obtained in step 5 by the correction factor to obtain a corrected value of G .

Angular acceleration and torque

Studies the relationship between the angular acceleration of a body and the torque applied to that body.

Outline: Using data capture software, the angular velocity of different masses in a pulley system are recorded. From this data, the relationship between angular acceleration and torque is investigated.

Concepts: Newton's second law
 $T = I\alpha$ (Torque = moment of inertia * angular acceleration)



Equipment: Mass carrier (inc. range of masses)
Retort stand with pulley
Pasco rotary motion sensor with interface and computer software

Notes: Set up the DataStudio application as follows:

1. in the 'Experimental Set-up' window, double-click 'rotary motion sensor'
2. double-click the rotary motion sensor picture to select 'sensor properties'
3. in the 'Measurement' window of sensor properties, choose 'Angular velocity, Ch1&2 (rad/s)' only
4. in the 'Displays' list, double-click the 'graph' icon

To capture data:

1. release the carrier, immediately click the 'start' button
2. click the 'stop' button just before the mass reaches the ground

Mass on a spiral spring

A simple mass on a spring is used to calculate the spring constant, k , and determine the gravitational acceleration, g .

Outline: Data capture software and an ultra sound sensor is used to record the movement of a spring under different conditions. The first part of this experiment investigates the relationship between the period of oscillation and mass; the data taken is used to determine the spring constant, k . The second part measures the extension of the spring with known masses and with the determination of k , a value for the gravitational acceleration is calculated.

Concepts: Simple harmonic motion (SHM)
Gravitational acceleration



Equipment:

Mass on a spring apparatus inc. spring, stand, spring support, pointer, $\frac{1}{2}$ metre stick

Mass carrier (inc. range of masses)

Balance

Pasco motion sensor with interface and computer software

We also have a manual version of this experiment, using various springs with different spring constants. In this experiment, the student takes readings off a scale and uses a stopwatch to measure the period of oscillation.

Notes: When extending the spring to begin an oscillation, do NOT over extend the spring as this creates chaotic motion.

Set up the DataStudio application as follows:

1. in the 'Experimental Set-up' window, double-click 'motion sensor'
2. double-click the motion sensor picture to select 'sensor properties'
3. in the 'Measurement' window of sensor properties, choose 'Position, Ch1&2 (m)' only
4. in the 'Displays' list, double-click the 'graph' icon

Hooke's Law

Study of Hooke's law using compression and extension of various springs.

Outline: Force is applied to several different springs, measured by a Force Sensor, the extension/compression is also noted. Analysis of the data, allows the calculation of the spring constant, k , for each spring.

Concepts: Hooke's Law



Equipment: Various springs
Table clamp
Metre stick
Pasco Force Sensor with interface and computer software

Notes: Set up the DataStudio application as follows:

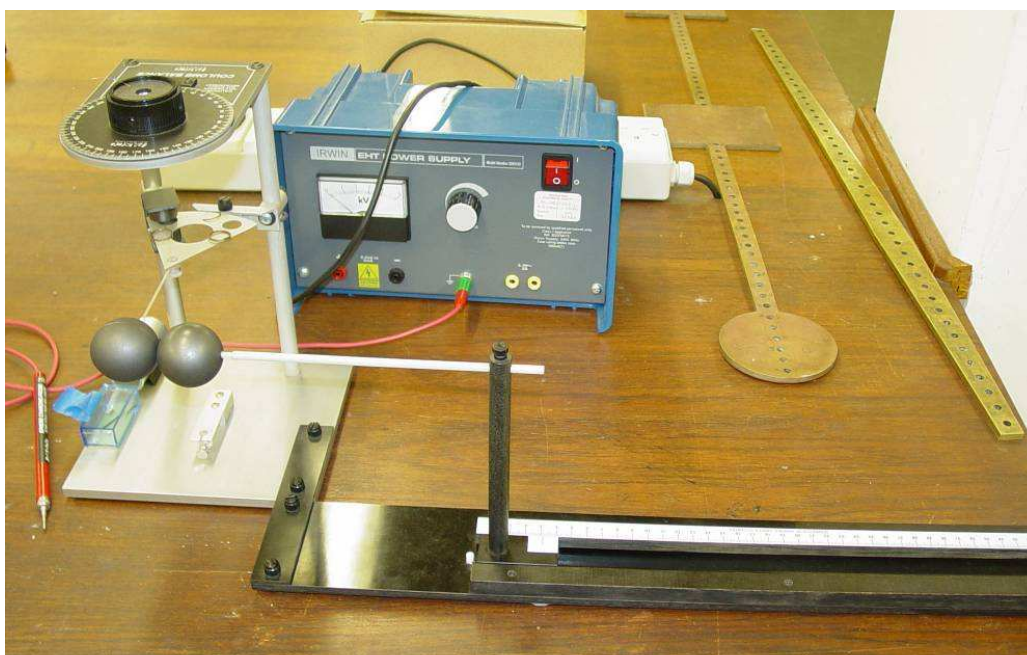
1. in File menu, click 'Open New Activity'
2. load either 'HookesLawExtension(PP).ds' or 'HookesLawCompression(PP).ds'
3. press 'Start' to begin measurements
4. press 'Keep' to save current measurement

Coulomb's Law

Studies the nature of Coulomb's Law, which describes the force between two charged particles.

Outline: This experiment is designed to study Coulomb's Law using two spheres that can be charged with the same type of charge to repel each other. One sphere is connected to a torsion wire, knowing the torsion constant of the wire allows force to be related to the torsion angle measured. There are two variables that can be investigated, force vs. distance and force vs. charge.

Concepts: Coulomb's Law
Inverse square relationships



Equipment: Coulomb's Law apparatus
HT variable power supply (0-5kV)

Safety Notes and Example Experiment: Please see next page.

Example Coulomb's Law Experiment – force vs distance

1. **Fully discharge both spheres by touching them with an earthed probe.**
Move the sliding sphere as far as possible from the suspended sphere. Set the torsion dial to 0° . Zero the torsion balance by rotating the bottom torsion wire retainer until the index marks are aligned.
2. Set the H.T. supply to its maximum voltage and charge both spheres by touching them each with the probe. **Immediately switch the H.T. supply off** (to reduce high voltage leakage effects).
3. Bring the sliding sphere to the 20.0 cm mark. Adjust the torsion knob to restore balance. (Index marks again aligned.) Record the distance, r , and the angle, θ .
4. Move the sliding sphere to its maximum distance away from the suspended sphere again, and discharge and recharge both spheres to the same voltage. Bring the sliding sphere back to the 20.00 cm mark and re-measure the torsion angle. Repeat until the torsion angle is repeatable to $\pm 1^\circ$.
5. Repeat steps 2 to 4 for various separations.

Analysis Notes:

The correction factor, k , is equal to $1 - \frac{4a^3}{r^3}$, where a is the radius of the spheres, and r is the separation of the spheres. Since the spheres in this apparatus have a radius of 1.9 cm, this correction factor becomes $1 - \frac{27.44}{r^3}$, (r is measured in cm.)

Divide all of the values of θ by the correction factor k , to obtain $\theta_{\text{corrected}}$.

The torsion constant, c , of the suspension wire used in this apparatus has been measured as 1.76 μN per degree. Calculate the values of force using $F = c\theta_{\text{corrected}}$.

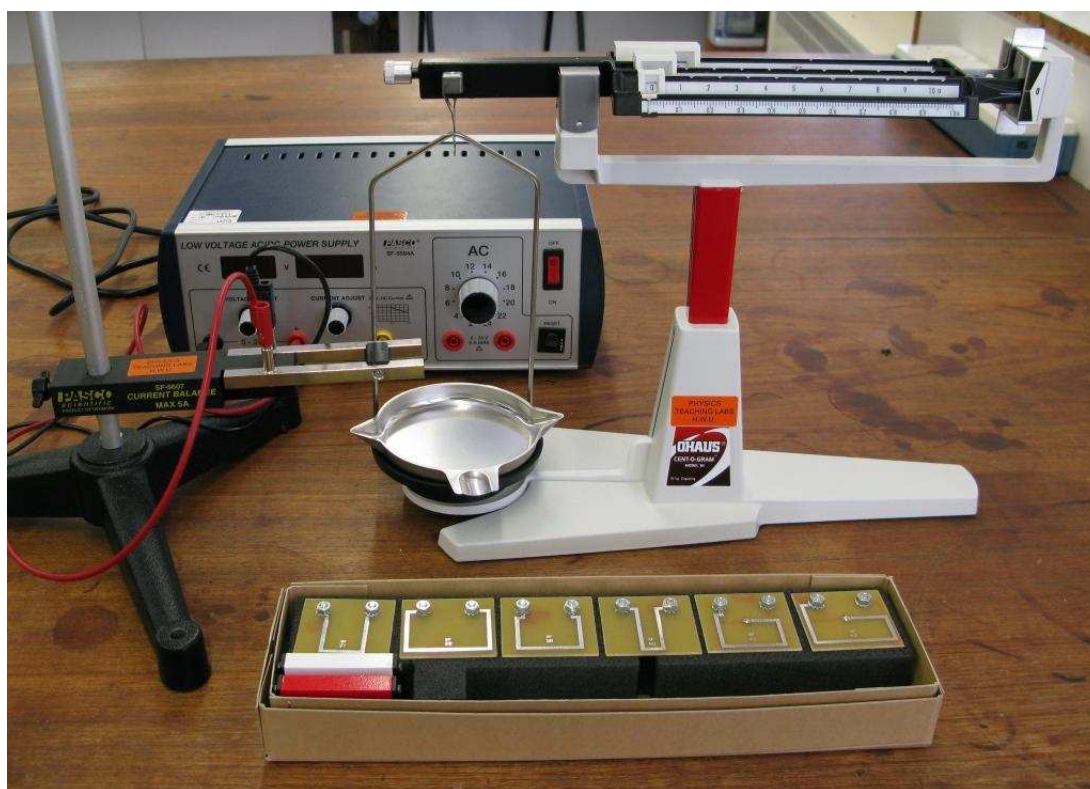
Plot a graph of $\frac{1}{r^2}$ -v- F , and deduce the relationship.

Force on a current-carrying conductor

Studies the nature of the force produced when a wire with a current flowing through it is placed in a magnetic field.

Outline: The experiment is designed to verify the relationship between current and force. It can also be used to show that there is a link between magnetic field and force, as well as angle and force.

Concepts: Relationship between current and magnetism
 $F = BIL \sin \theta$ (Force = magnetic field * current * length * sine angle)



Equipment: power supply (up to 8A @10V)
 Ohaus Cent-o-gram balance
 Current balance assembly with various lengths of conductor
 Pairs of magnets with yoke assembly
 Current balance accessory (angle exp)
 Wider magnet set (angle exp)

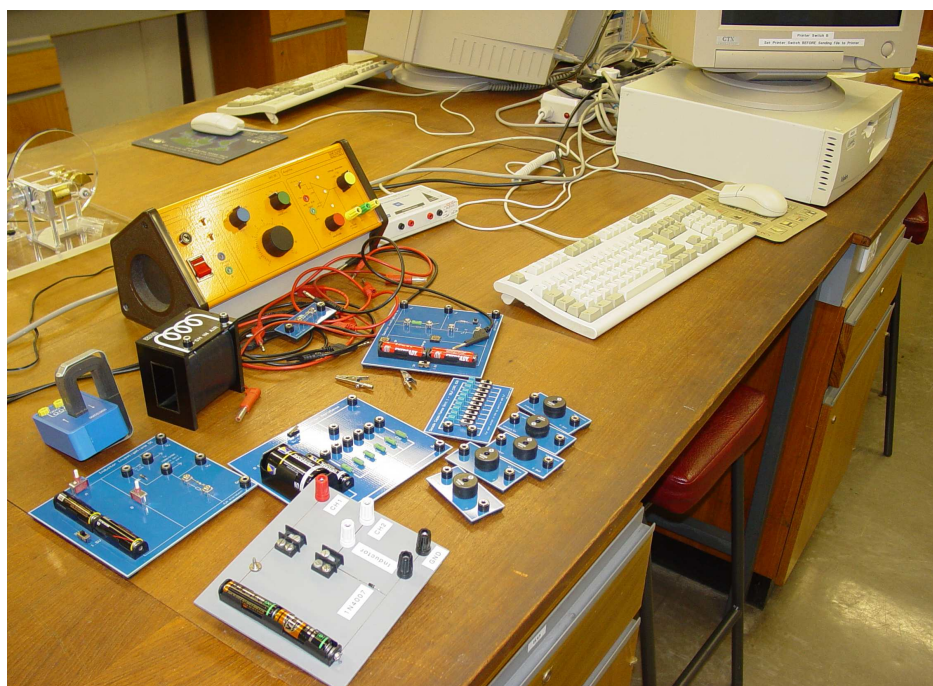
Current and frequency in an inductive circuit

Studies the relationship between current and frequency in an inductive circuit.

Outline: This experiment is designed to show the relationship between current and frequency in an inductive circuit.
Further work: We have capacitance and internal resistance circuits which can also be investigated.

There is a lack of Error Analysis in electronics experiments, therefore pupils carrying out these types of experiments must consider how to include error analysis in their report.

Concepts: Resistance
Inductance
Reactance
Circuit impedance



Equipment: Signal generator
Circuit (2.2mH inductor & 0.33 Ω resistor)
Connecting leads
Alba interface with computer software

Notes: Set up the Alba application as follows:
1. click 'Load an Application'
2. load the 'AC-Inductor Current/Frequency' application
3. follow the on-screen instructions, the voltage should be set at ~2.00V and remain constant

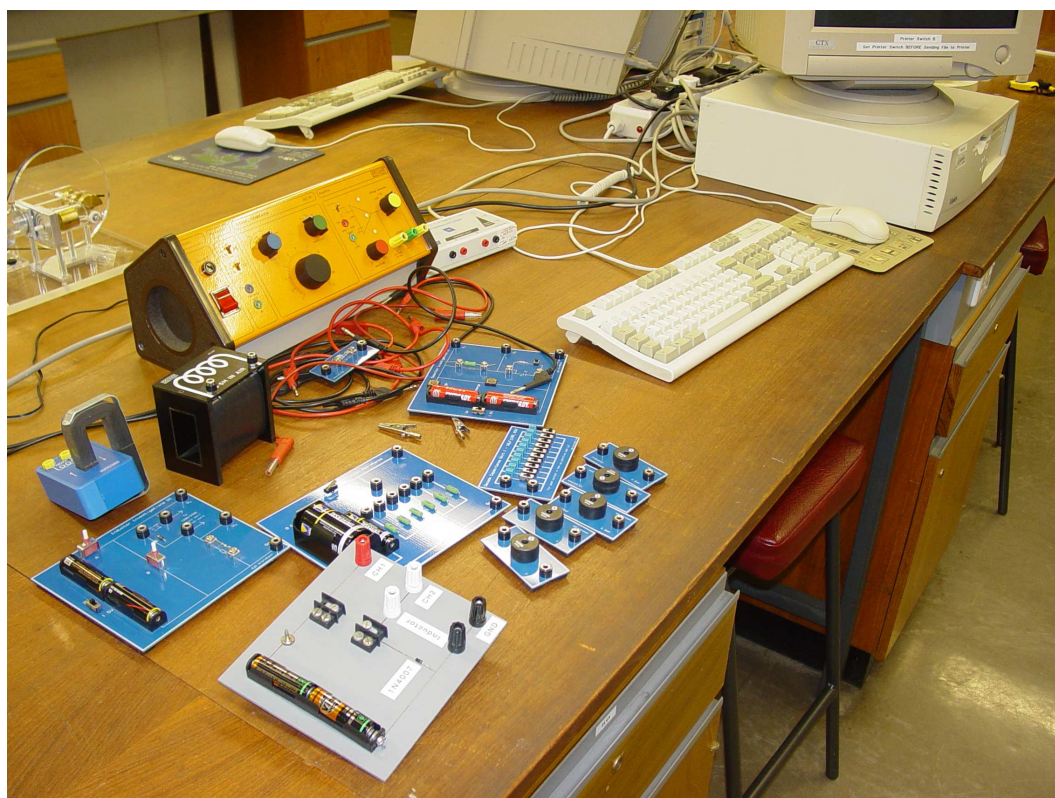
Self inductance of a coil

Determines the self-inductance of a coil using a simple circuit and computer interface.

Outline: The inductive circuit from the previous experiment is used with the data capture software to determine a value for the self inductance of a coil.

There is a lack of Error Analysis in electronics experiments, therefore pupils carrying out these types of experiments must consider how to include error analysis in their report.

Concepts: Self induced emf of an inductor



Equipment: Inductor circuit
Connecting leads
Alba interface with computer software

Notes: Set up the Alba application as follows:
1. click 'Load an Application'
2. load the 'Inductors-di/dt at Switch-on' application
3. follow the on-screen instructions

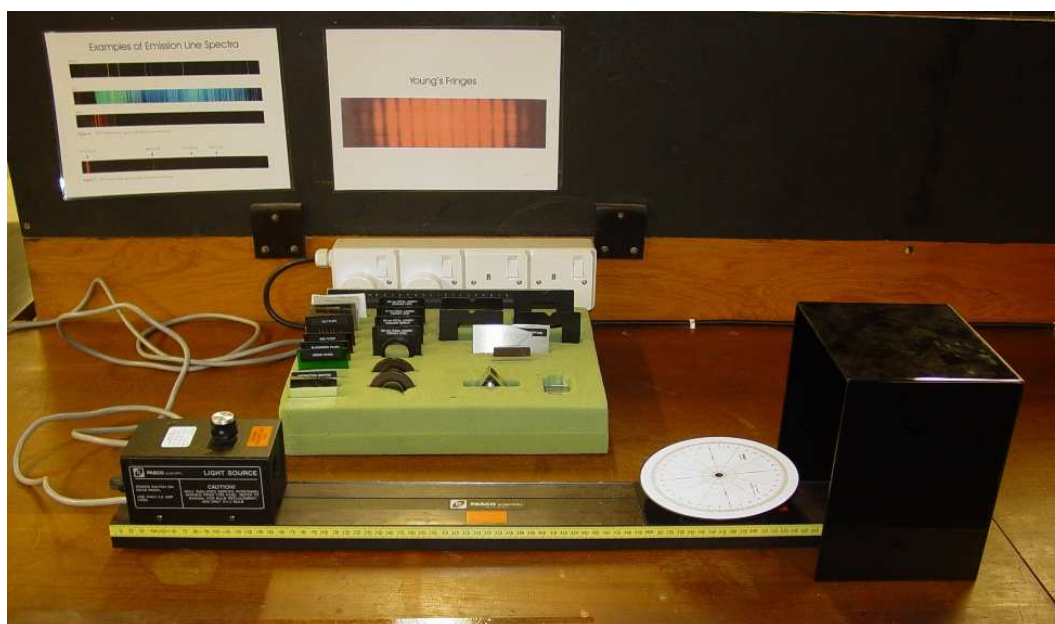
Thin lenses

Uses simple equations to describe the focal length and magnification of thin lenses.

Outline: The kit provided is used to investigate the properties of thin lenses.
Suggested experiments:

1. Studying Magnification using a 75mm convex lens, light source and viewing screen.
2. Studying Lensmaker Equation using a 75mm convex lens, light source and viewing screen
3. Determining the focal length of a converging lens by the Autocollimation Method using a plane mirror, opaque cross target and a concave lens.

Concepts: Thin lens formula
Convex/concave lenses



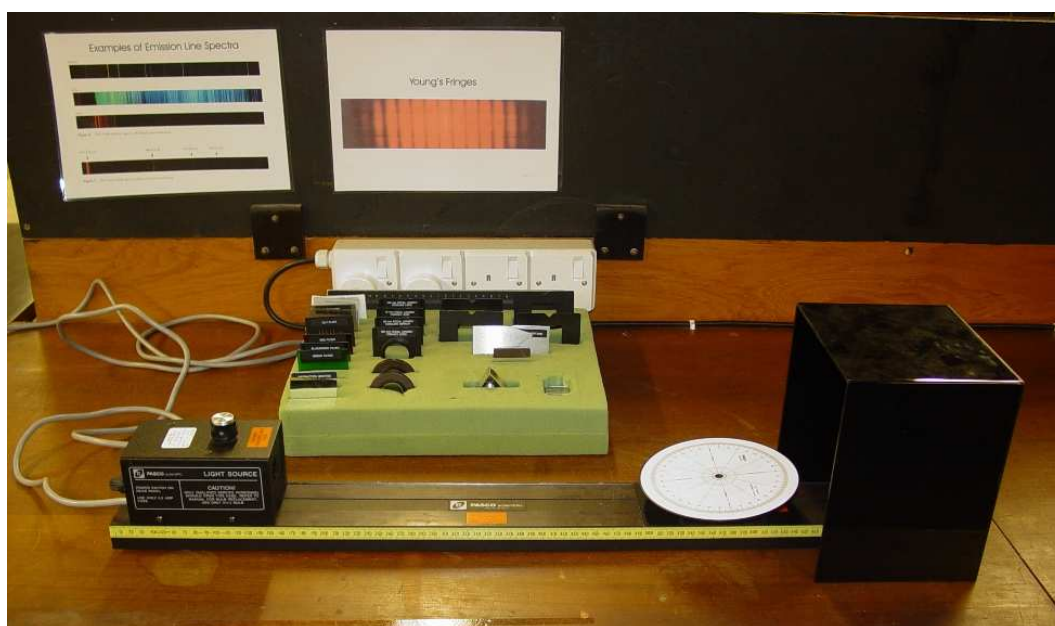
Equipment: Pasco Optics Kit inc light source, optical bench, ray table, black shroud, various lenses, filters, gratings with stands.

Reflection and refraction

Studies the law of reflection and the law of refraction (Snell's law)

Outline: Using the parallel ray lens, slit plate and slit mask, set up the optics kit to produce a single ray through the centre of the inclined ray table. Once completed use the ray to investigate the Law of Reflection and Snell's Law (Law of Refraction) using a plane mirror and a cylindrical lens (with $n=1.5$).

Concepts: Reflection
Refraction
Snell's Law
Critical angle



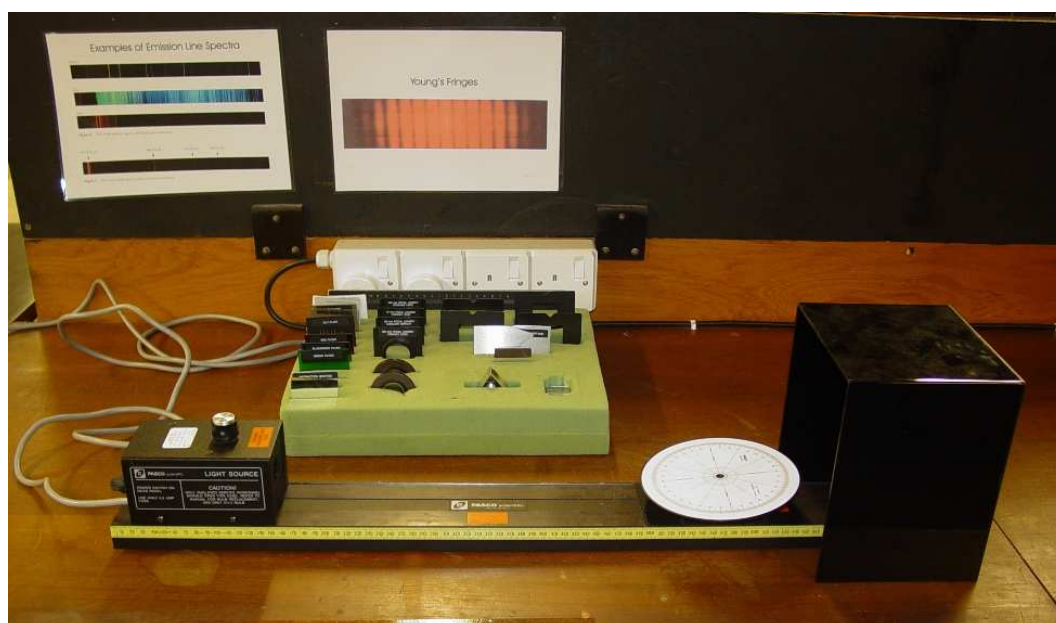
Equipment: Pasco Optics Kit inc light source, optical bench, ray table, black shroud, various lenses, filters, gratings with stands.

Optical polarization & Brewster's angle

Studies the nature of the polarization of light and polarization induced through reflection. Works well in conjunction with the next experiment.

Outline: The first part of this experiment investigates light from a ray box and the effect of both a single polarizer and two polarizers together on the light. In the second part, polarization by reflection and Brewster's angle are investigated.
Further work: Investigate LCD displays, polarised sunglasses and view a digital watch display through a polarizer.

Concepts: Polarization of light
Brewster's angle



Equipment: Pasco Optics Kit inc light source, optical bench, ray table, black shroud, 2 linear polarisers (which transmit only light that is polarised along the plane defined by the 0° and 180° marks), Semicircular perspex block.

Notes: This experiment could also be carried out using a laser. If so DO NOT look directly at the laser beam or its reflection.
Please see the next page for an outline of the Brewster's Angle Experiment.

Polarization by reflection – Brewster's angle

1. Set up the equipment so that a single ray of light from the ray box is both reflected and refracted at the flat face of the semicircular Perspex block.
2. View the reflected ray of light through a single polarizer. You should be able to look through the polarizer at the filament of the light source (as reflected off the Perspex block). Rotate the polarizer while viewing the filament. Comment on your observations, with regard to whether the reflected ray of light is polarised.
3. Adjust the apparatus so that the angle between the reflected and refracted rays is 90° . View the reflected ray of light through the polarizer. Comment on the extent of the polarization that is now observed and state the direction of polarisation of the reflected ray in relation to the reflecting surface.

Polarization – Malus' Law

Investigates the intensity of polarized light passing through a second polarizer set at an angle to the first polarizer. Works well in conjunction with the previous experiment.

Outline: This experiment is designed to verify the relationship between the intensity of the transmitted light through two polarizers, one acting as a polarizer and one as an analyser, and the angle between the axes of the two polarizers – Malus' Law. Two different types of light can be used, white light and a HeNe laser. The computer measures the intensity of the light reaching the light sensor.

Concepts: Malus' Law



Equipment: Pasco Optics Kit
Laser ray box
Alba light sensor with interface and computer software

Notes: Calculate the intensity as a percentage of the maximum intensity, $I_{(\% \max)}$, for each angle using $I_{(\% \max)} = \frac{I - I_{\min}}{I_0 - I_{\min}} \times 100$.

Plot a graph of $\cos^2 \theta$ -v- $I_{(\% \max)}$, and deduce the relationship.

Set up the Alba application as follows:

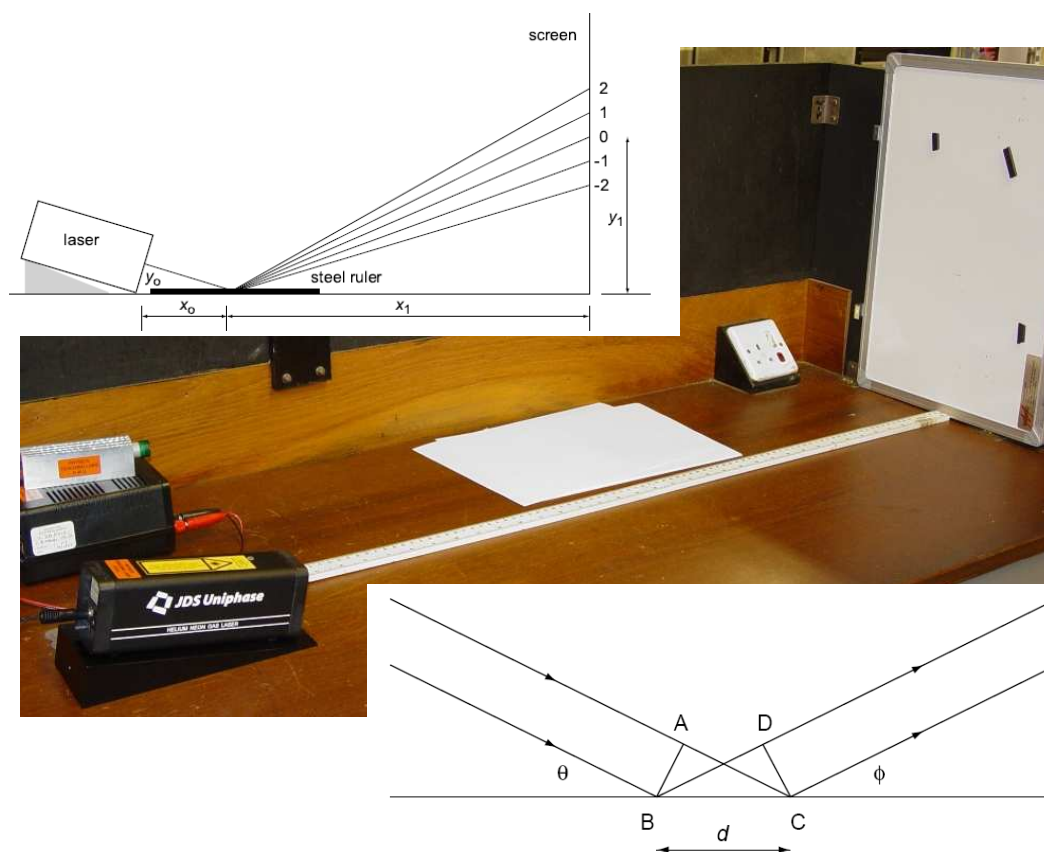
1. click 'Load an Application'
 2. load the 'Analogue Snapshot' application
 3. initially set up for measuring angle vs intensity
- DO NOT look directly at the laser beam.

Wavelength of light

Uses optical interference to determine the wavelength of red and green laser light. This wavelength can then be used to determine the track spacing on a standard CD. Works well in conjunction with the next experiment.

Outline: Laser light incident on a steel ruler with well defined rulings is reflected and produces an interference pattern onto a vertical screen. From this interference pattern the wavelength of the light can be calculated. Two lasers of different wavelength are provided.

Concepts: Optical interference
Young's double slit experiment



Equipment: HeNe laser (class 2)
Green laser (class 2)
Metal wedge
Steel ruler
White screen
Metre stick

Required equation: $\cos \theta - \cos \phi = \frac{n\lambda}{d}$
where θ , ϕ , d are shown above
 λ = wavelength of light

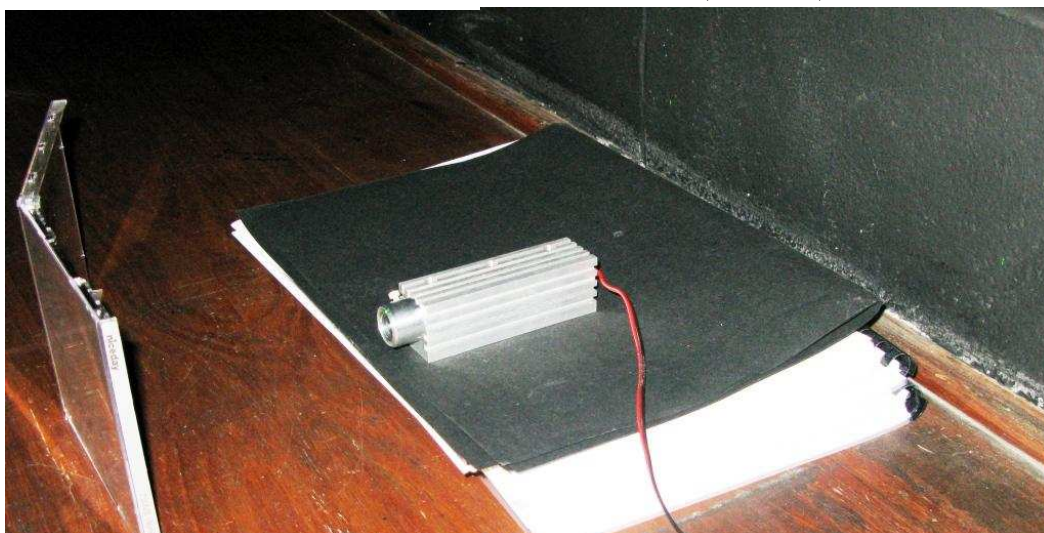
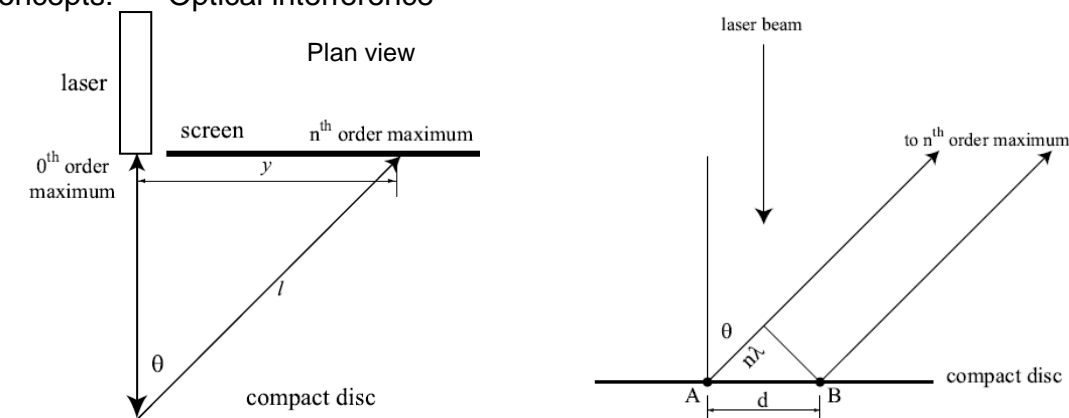
Notes: DO NOT look directly at the laser beam.

Determining the track spacing on a CD using a laser

Uses the known wavelength of light and optical interference to determine the track spacing of a CD. Works well in conjunction with previous experiment.

Outline: Laser light when reflected off a CD can produce an interference pattern. If the wavelength of this light is known, then the track spacing of the CD can be calculated. Two lasers of different wavelength are provided for this experiment.
Further work: This method can also be used to determine the track spacing of a mini disc or a DVD.

Concepts: Optical interference



Equipment: HeNe laser (class 2)
Green laser (class 2)
CD/DVD in jewel case
White screen
Metre stick

Notes: DO NOT look directly at the laser beam.

Speed of Light

The speed of light is determined by measuring the physical time a light pulse takes to travel a known distance. A pulsed light source, optical detector mirror and oscilloscope are used to measure the delay time between sending and receiving a pulse as it propagates various distances.

Outline: The dual channel oscilloscope with external trigger allows the user to note the time a beam of light is transmitted, as well as the time it is detected by the receiver. By repeating this measurement over various distances the speed of light can be determined.

Concepts: Speed of light



Equipment: UNILAB Speed of Light Kit
Transmitter, Receiver, Power supply, Large fresnel lens,
Small fresnel lens, 3 BNC-BNC leads, Power supply lead,
Fibre optic cable, Large mirror
Dual channel oscilloscope
10m tape measure

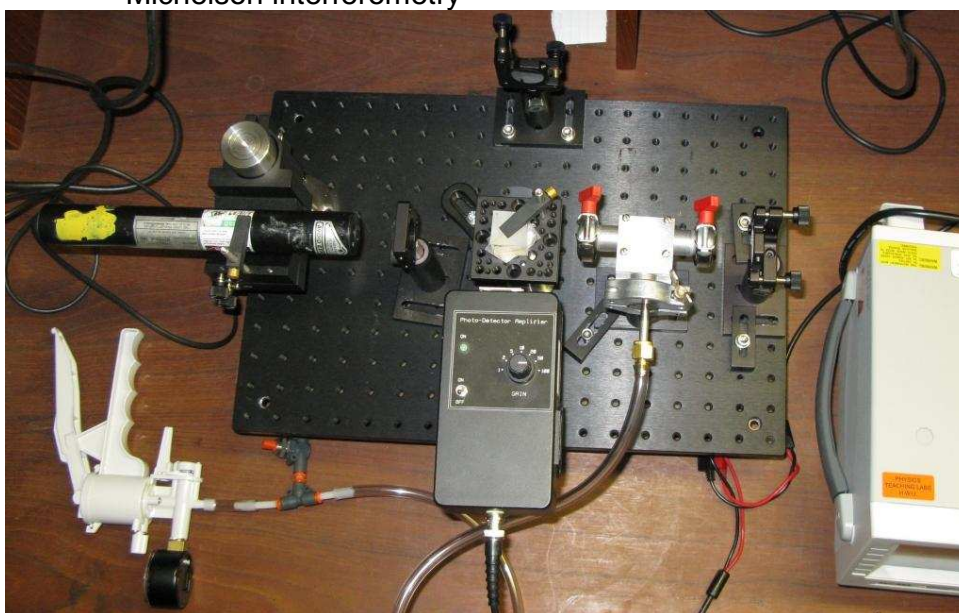
Notes : Do NOT look directly at the LED in the transmitter.
There is an instruction booklet provided with this experiment.

Measurement of Refractive Index of Air Using Michelson Interferometer

A Michelson interferometer is a simple optical system used for investigating the effect of optical interference. In this experiment a gas cell is used to evacuate air from part of one of the two optical paths. The resulting change in measured fringes is then used to determine the refractive index of air.

Outline : A Michelson interferometer system is set-up and aligned using standard research laboratory grade optical components. A gas cell, hand pump and optical detector can then be used to determine the refractive index of air by measuring the change in interference pattern as a function of air volume inside the gas cell.

Concepts : Optical interference
Michelson interferometry



Equipment:	He-Ne laser & mount	Oscilloscope
	Mirrors & mounts	Gas Cell
	Optical beamsplitters & mount	PASCO hand pump
	Optical detector	Breadboard

Notes :

1. Do NOT look directly at the laser beam.
2. All components are mounted, do not remove the components from the bases.
3. The breadboard sits on a large piece of foam to limit vibrations.
4. Please turn the detector off when not using it to conserve battery power.

Alignment Hints

1. The laser should run parallel to the breadboard and perpendicular to one of the edges. It should strike each optical component roughly in the centre.
2. When aligning the mirrors align one mirror at a time and align such that the reflection from that mirror travels back into the laser aperture.
3. The lens should be placed in front of the laser in order to see the fringes clearly.

Experiment Hints

The oscilloscope should be set to 1 channel with around 20 mV per division and a time window of 500 ms. The oscilloscope must be operating in ROLL mode, accessed via the horizontal menu. It is possible to freeze the oscilloscope display by pressing the Run/Stop button.

The centre of the interference pattern should be studied for the best results.

Analysis

The gradient of the graph of “number of fringes vs pressure” gives the refractive index of air using the following expression:

$$n_{air} = 1 + \frac{\Delta N}{\Delta P} \frac{\lambda}{2L} P_{atm}$$

Where L is the length of the gas cell, P_{atm} is atmospheric pressure (roughly 1010 mbar) and λ the wavelength of the light used (633 nm).

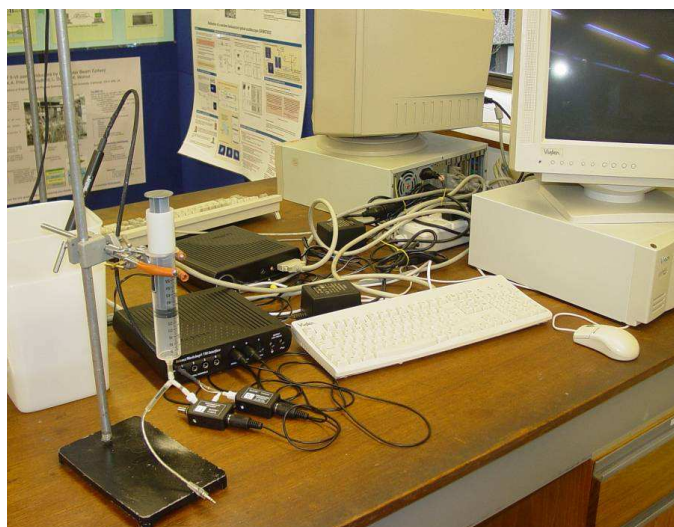
Note: When measuring the length of the gas cell, do NOT include the end caps which are each 5.5mm thick.

Ideal Gas Law

Determine number of moles in a gas sample.

Outline: This experiment investigates the Ideal Gas Law to determine the number of moles in a chosen volume of gas.

Concepts: Connection between pressure, temperature and volume of a gas, Ideal gas Law



Equipment:

Ideal Gas Law syringe,
Pasco pressure/temperature
sensors with interface and
computer software.

- Notes:
- Set up the DataStudio application as follows:
1. in File menu, click 'Open New Activity'
 2. load 'Ideal Gas Law.ds'
 3. press 'Start' to begin measurements
 4. when asked enter the volume of the plunger
 5. press 'Keep' to save current measurement
 6. compress plunger by ~5cl, allow pressure and temperature to stabilise
 7. hit 'Keep' and enter current volume as before
 8. note any fluctuations in pressure and temperature to include in your error analysis
 9. compress to new volume and repeat 6 – 8 to get a series of results

Determination of Absolute Zero

Use Ideal Gas Law to find 0K .

Outline: This experiment measures the pressure of a fixed volume of gas as a function of temperature and uses the linear relationship between the two to determine absolute zero.

Concepts: Ideal Gas Law
Absolute zero temperature



Equipment:

Absolute Zero apparatus
2 plastic buckets (boiling water & ice)
Pasco pressure/temperature sensors with interface and computer software.

Notes:

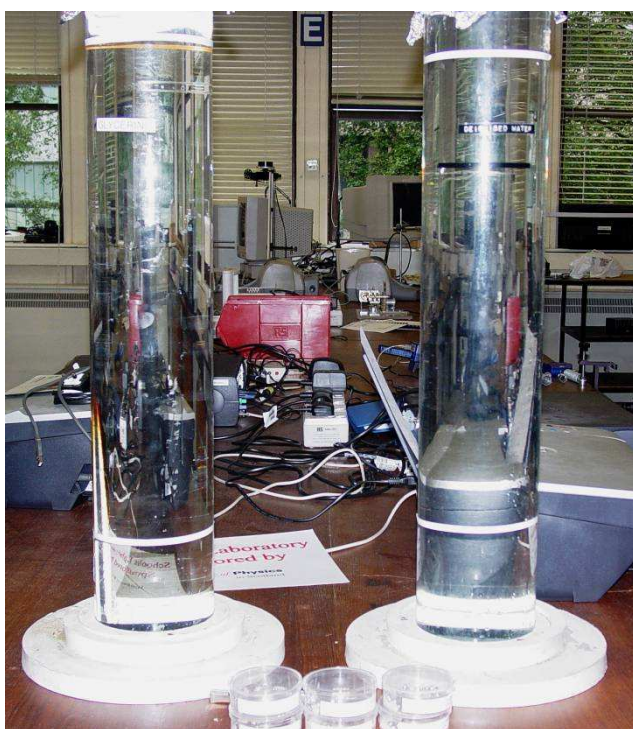
1. Half fill one bucket with boiling water and the other with very cold water/ice.
2. Connect the hose fitting from the Absolute Zero Apparatus to the Pressure Sensor (it fits like a BNC plug). Connect the stereo plug from the apparatus to the Temperature Sensor.
3. Load the Datastudio experiment "Absolute zero" from 'Open New Activity'. Click the 'Start' button.
4. Place the sphere of the apparatus in the hot water bath, and keep the sphere completely submerged.
5. Watch the Digits display of temperature. When the display stops changing, click on the 'Keep' button. Manually note any fluctuations in temperature or pressure: these should be included in your error analysis.
6. Gradually cool the water bath by adding cold water or some ice cubes. If the container becomes too full, dump out some of the water, but always have enough water to keep the apparatus completely submerged. Cool the bath by a few degrees, and repeat step (4).
7. Repeat steps 4 through 6, for temperatures down as low as you can go, and then click on the **Stop** button to end recording.

Viscosity

Determines the viscosity of glycerine and water using the terminal velocity of falling beads through the liquid.

Outline: The viscosity of two fluids (deionised water and glycerine) will be measured.

Concepts: Viscosity
Stokes Law
Archimedes Principle
Newton's Laws



Densities required:

Liquids at 20°C
glycerine $\rho = 1.261 \text{ g/cm}^3$
deionised water $\rho = 1.0 \text{ g/cm}^3$

Spheres
stainless steel $\rho = 8.0 \text{ g/cm}^3$
nylon $\rho = 1.15 \text{ g/cm}^3$

Required equation:

$$V_T = \frac{2}{9} \frac{r^2 (\rho - \rho_F) g}{\eta}$$

V_T = terminal velocity of sphere
 r = sphere radius
 ρ = density of the sphere
 ρ_F = density of the fluid
 g = acceleration due to gravity
 η = viscosity of the fluid.

Equipment: 2 tubes of liquid (glycerine & deionised water)
Various sizes of nylon & stainless steel spheres
Vernier callipers, Balance, Thermometer, Tweezers
Stop-watch
Metre stick

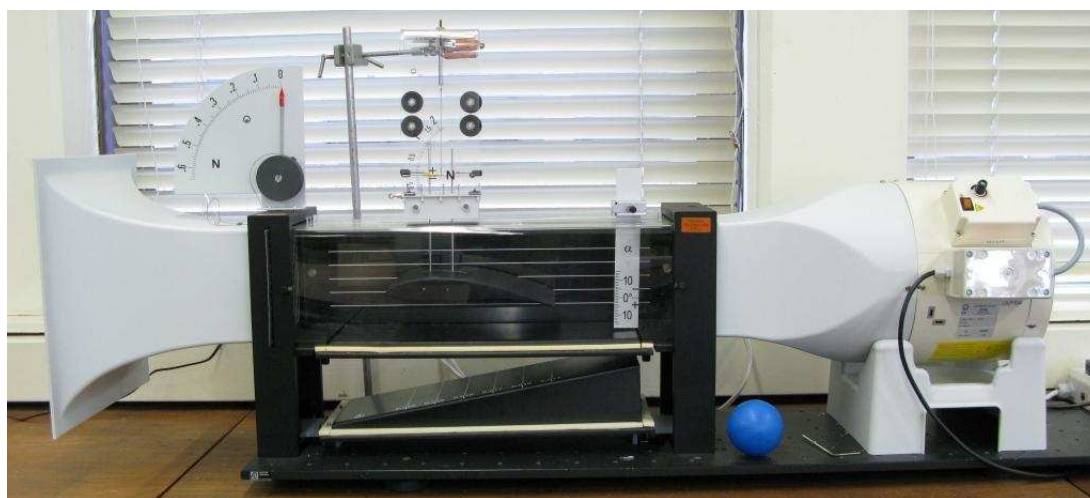
Notes: Do not place the nylon spheres in the glycerine, they simply float.
Liquids can be messy, please be careful when handling, especially the glycerine.
Thoroughly wipe any equipment inserted into the liquids, but NOT the spheres. Do NOT remove the spheres, ask a demonstrator.

Experimental Aerodynamics

A wind tunnel with variable air speed is used to explore several aspects of simple aerodynamics. The provided equipment can be used to verify Bernoulli's equation, determine the drag coefficient of a sphere and examine the drag and lift coefficients of a wing section.

Outline : There are three separate experiments that can be carried out using the wind tunnel. Using the Bernoulli ramp and the static pressure tubes, Bernoulli's equation can be verified. The drag coefficient of a mounted sphere can be measured. By varying the wind speed and angle of attack of a wing section, the drag and lift coefficients can be investigated.

Concepts : Bernoulli's equation
Drag and Lift



Equipment:	Leybold wind tunnel	Anemometer
	Bernoulli ramp	Static pressure tubes and reader
	Trolley	Mounted sphere
	Wing section	Lift indicator
	Angle indicator	Flat floor surface
	Clamp stand	

Notes :

Many components are fragile and easily damaged. Do not use excessive force to assemble/dismantle the equipment

The anemometer head contains a fragile temperature sensor. Care should be taken to ensure this does not come into contact with anything that could damage the sensor.

There are a number of potential experiments that may be performed using the provided equipment. Some important physics concepts that can be investigated are summarized below.

1. Bernoulli's Equation

Bernoulli's law, which gives the relationship between static pressure, p , and flow velocity, v , for a horizontal frictionless flow between two points, can be simplified under certain conditions to the continuity equation:

$$v_0 A_0 = v_1 A_1 \quad (1)$$

Where the flow velocities v_0 and v_1 are at two different locations in the wind tunnel with cross-sectional areas A_0 and A_1 .

2. Drag coefficient of a sphere

The drag coefficient C_d of an object at low air speeds (non turbulent) is given by:

$$C_d = \frac{D}{\rho A V^2 / 2} \quad (2)$$

Where D = drag, ρ = density, V = the velocity and A is the projected area of the test object.

3. Lift coefficient of a wing section

An aerofoil (or wing) generates lift, L , as a result of lower air pressure above the wing arising from higher airspeed above the wing. The lift coefficient, C_L , is given by:

$$C_L = \frac{L}{\rho A V^2 / 2} \quad (3)$$

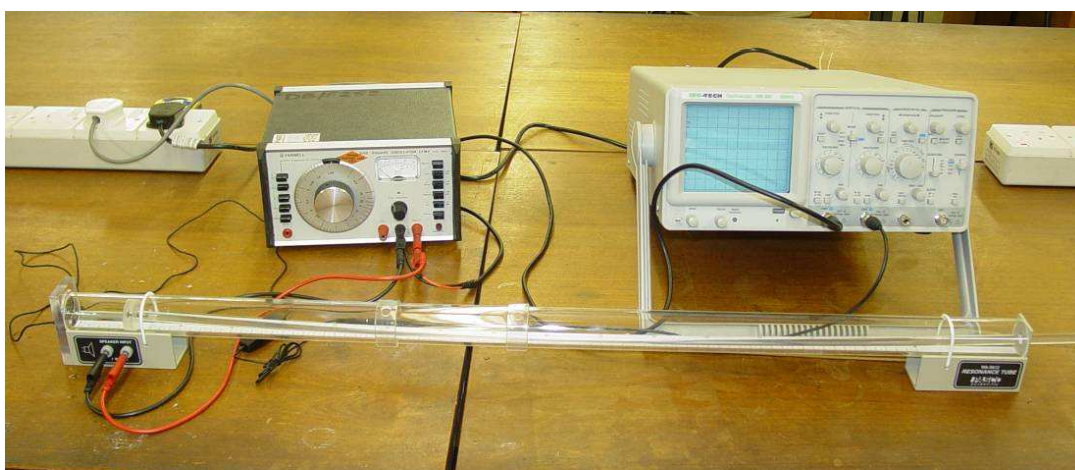
Where ρ = density, V = the velocity and A = the projected area of the test object.

Resonance Tube

Standing waves in a tube, Measurement of the speed of sound.

Outline: The first part involves a signal generator connected to a driver unit and string, fixed at one end, which can be used to visually study resonant frequencies. The second part involves the set up of standing waves inside a Resonance Tube and the use of a miniature microphone to determine the characteristics of the standing waves.

Concepts: Sound waves
Standing waves
Resonance

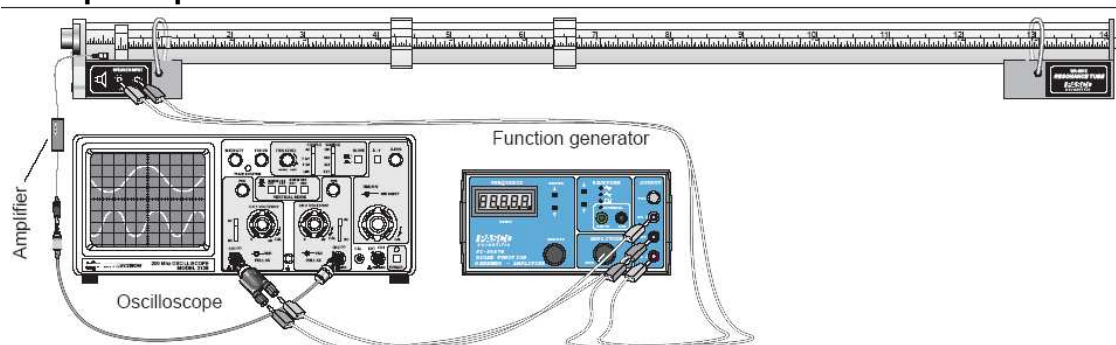


Equipment:

String fixed to support pillar and wave driver
2 signal generators
Resonance tube
Oscilloscope
Amplifier

Warnings: You can damage the speaker by overdriving it. The sound from the speaker should be clearly audible but not too loud.
Please turn the amplifier off when you are not using it in order to conserve battery power.
Use the grey Farnell LFM4 signal generator for this experiment.
Please see next page for example experiment.

Example Experiment



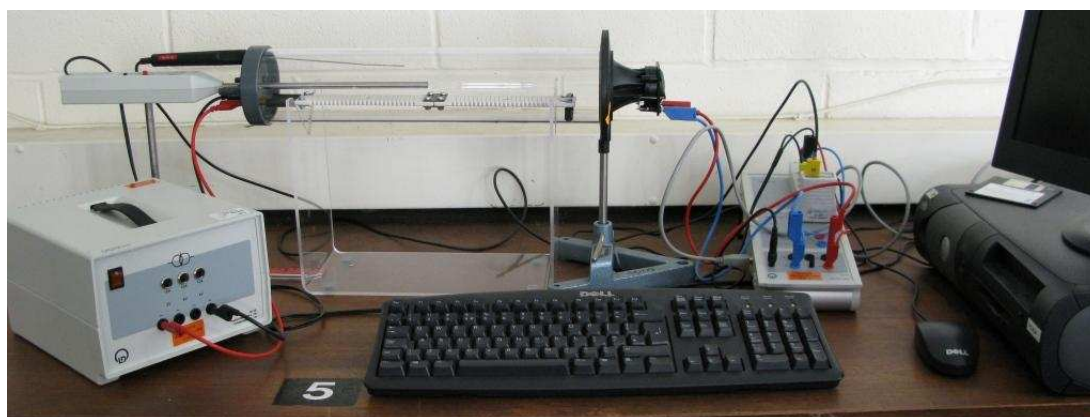
1. Set up the equipment as shown above but leave the piston out of the tube so there is an open tube. Set the oscilloscope time base to 5 ms/div and the voltage range to 5 mV/div. Set the function generator to produce a 500 Hz signal at around a few volts. Ask for help if you are not sure how to use an oscilloscope. You should hear a distinct sound from the speaker, if not turn the frequency/voltage up slightly until you do. Do not exceed 5 volts.
2. Turn the frequency up slightly whilst watching the oscilloscope signal from the microphone. At specific frequencies the oscilloscope signal should peak. This should coincide with a slight decrease in the sound level. This frequency is a resonant frequency of the tube. Continue increasing the frequency until you find another resonance. Repeat until you find at least 5. You need to try and find the lowest resonance frequency so try turning down the frequency from your initial starting frequency to see if there are any lower resonances. Note that the frequency stated by the function generator may not be correct: you should use the oscilloscope to accurately determine your frequency.
3. Divide each frequency by the lowest resonant frequency you measured. You should get a series of whole numbers (why?).
4. Repeat steps 2-3 with a closed tube and compare with your results from 3.

Speed of Sound

The speed of sound is determined by measuring the physical time a sound wave takes to travel a known distance. Computer software measures the time delay between a sound pulse generated by the loudspeaker and the detection of that pulse by the microphone. A heater element allows the temperature of the air between the microphone and loudspeaker to be increased, so that the relationship between the speed of sound and air temperature can be examined.

Outline : The equipment provided is used to determine the speed of sound by comparing the time taken for a sound pulse to travel various distances. The speed of sound at room temperature can be measured then, using the heater element, the speed of sound can be measured at various temperatures.

Concepts : Speed of sound in air



Equipment:	Computer Plastic tube on stand Loudspeaker on stand Temperature probe Heater power supply	Sensor CASSY interface unit Heater element Microphone on stand Ruler
-------------------	---	---

Notes :

- Do NOT heat apparatus above 80°C as above this temperature the plastic tube can be damaged.
- Do NOT exceed 25V for the heating element (~5A).
- If the measured interval is >1s, the microphone may have switched off, simply turn it on again.
- Set up the CASSYLab software as follows:
 1. Close settings window, press F3, load 'VelocityofSound.lab'
 2. Press F9 to store each measurement.
 3. Right click on results table to copy data to paste into Excel