getting it to work

PHYSICS EQUIPMENT *for* HIGH SCHOOLS

DEVELOPED BY

NSW DEPARTMENT OF SCHOOL EDUCATION IN ASSOCIATION WITH

AUSTRALIAN INSTITUTE OF PHYSICS

SCIENCE TEACHERS ASSOCIATION OF NSW

ETF

ACKNOWLEDGEMENTS

Getting it to Work - Physics Equipmentfor High Schools **was** written and developed by *Gay Hawkins* with the support of *Kerry Marston*; Senior Curriculum Officer (Science K-12), Curriculum Directorate of the NSW Department of School Education.

Credit and appreciation is also given to the following teachers for their written contributions to the manual.

Phil Kidd	- Video Camera
Anna Binnie	- Cloud Chamber
Jim Koen	- Linear Air Track
Pat Keam	- Spectroscope
Phil Wicks	- Cathode Ray Oscilloscope
Kevin Mahony	- Millikan's Oil Drop
Parry Jones	- Spectrometer
George Kelen	- Collisions in Two Dimensions and
	- Current Balance

A special thankyou to the Science Staff at St. George Girls' High School, and especially Pat Keam, Head Teacher, Science. Without her sound advice and support in making the school's science equipment and facilities available, this manual would not have been possible.

ERRATUM

"Curricula Directorate" in the foreword,
should read "Curriculum Directorate"

FOREWORD

The NSW Branch of the Australian Institute of Physics (AIP) has maintained close links with secondary and tertiary teaching of physics. The AIP has been involved in numerous projects to meet in-service training needs of teachers and to encourage secondary school students. At an in-service course in 1992 attended by the then Chairman, Professor Bob Clarke, it was suggested that one of the major deficiencies for non-physics specialist teachers was in using equipment for which there were no reasonable manuals or technical data. Out of this suggestion was borne a proposal put to the Education and Training Foundation (ETF) to support the development of an equipment manual for secondary school teachers. A joint application to ETF was successful and, in 1993, a steering committee consisting of representatives of the NSW Department of School Education, the NSW Branch of the AIP and the Science Teachers' Association of NSW set about preparing the manual.

The project benefited enormously from the expertise of Kerry Marston (Curricula Directorate), and Norman McCulla (Training and Development Directorate) of the NSW Department of School Education and of Yoka McCallum of the Science Teachers' Association (NSW). The committee initially identified equipment that was considered to be troublesome and then, with advice from specialist secondary teachers, reduced the list to a manageable number. The project then required a careful development of fact sheets which addressed the major issues associated with operating the equipment in a school environment. The normal problems associated with operating and maintaining the equipment were also addressed, as well as suggestions about demonstrations of particular value.

We hope that you find this manual useful and welcome any opportunity to assist in the use or development of further resource materials.

JOHN O'CONNOR — Chairman
DON NEELY — Secretary
NSW Branch of the Australian Institute of Physics

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INTRODUCTION

The use of equipment is an essential part of successful physics teaching. Many pieces of equipment are very specialised. To the unwary or inexperienced teacher of physics they may even appear mysterious. Even the instruction manuals, if they are still available may offer very little help. Much of this equipment can remain unused in school cupboards or storerooms.

The manual has been developed to assist teachers in the use of some of this equipment. It has been designed to offer a step-by-step practical guide in how to set up the equipment and get it to work. Practical hints are given on what to look for and check to ensure success and safety. There are a number of suggested learning experiences using the equipment for students in the senior physics classroom.

In selecting the pieces of equipment to be addressed in the manual consideration was given to the amount of difficulty teachers had indicated they had in using it, as well as its importance to the teaching of physics. The method for setting up and using each piece of equipment has been well researched and trialled by a number of teachers not experienced in using the equipment.

The equipment has been arranged alphabetically for ease of access. In the back of the manual you will find two indexes, one by physics topic and the other by individual learning experience. It is hoped that these will make the manual even more useful and easy to link into the senior physics syllabus and school programs.

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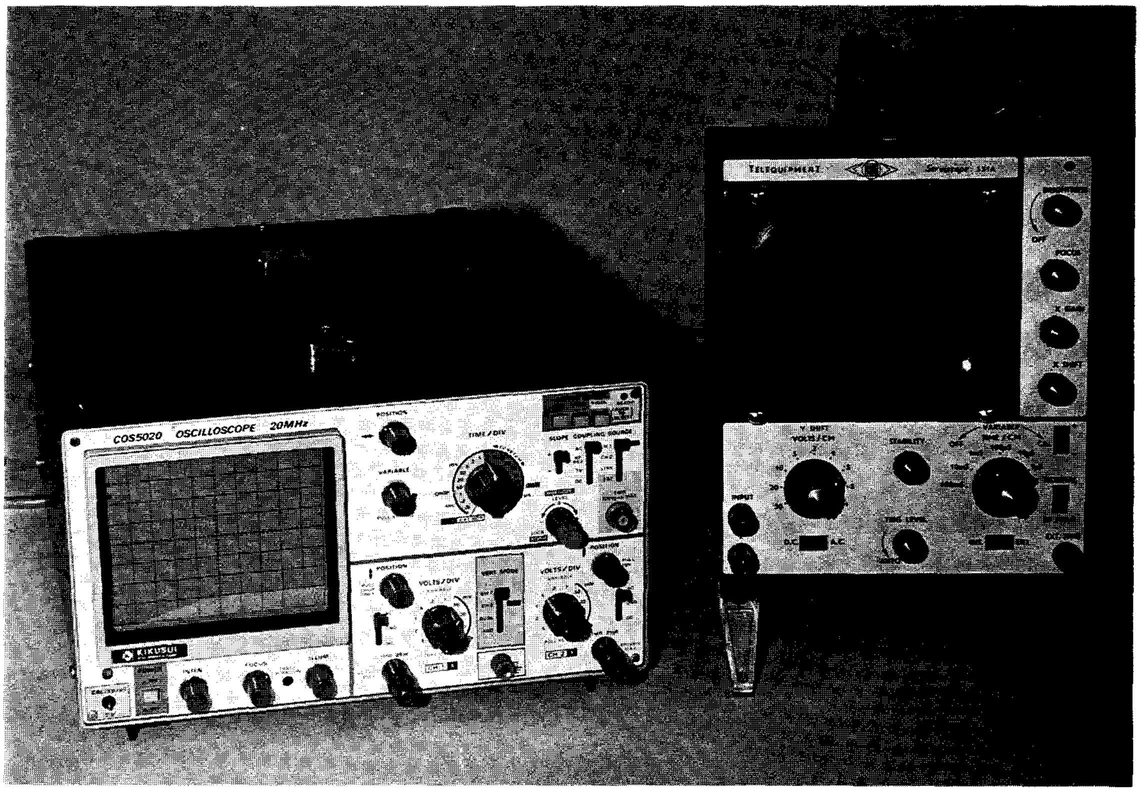
INDEX BY LEARNING EXPERIENCE

CATHODE RAY OSCILLOSCOPE



The cathode ray oscilloscope (CRO) is a device which converts electrical energy into a graphic image, called the trace. The heart of the device is a glass tube with a screen like a TV. When an alternating current (AC) is applied to the CRO inputs, it shows up as a simple wave form on the screen; direct current (DC) is displayed as a straight line. A voice, which has been converted to an electrical signal by a microphone, is shown on the screen as a complex wave form. The CRO is also a good device for measuring voltage because it has a very high internal resistance ($> 1\,M\Omega$) and does not interfere very much with the operation of the circuit under investigation. The trace can be analysed in terms of voltage (vertical axis measurements) and time (horizontal measurements).

SETTING UP AND USING THE CATHODE RAY OSCILLOSCOPE

X Extra equipment for the suggested learning experiences (numbers refer to appropriate experiences) includes:

- **2** power packs (2, 6, 8, 9)
- a small loudspeaker (readily available at Dick Smith's) (7)
- an audio oscillator/amplifier (5, 7, 8, 9)
- musical instruments such as guitar, violin, etc.
- a demonstration electric generator (1)
- a microphone (3, 7)
- leads
- 1.5V dry cell (1)
- tuning forks
- organ pipes (7)
- 1 metre of aerial wire (4)

- an air-core solenoid (10)
- a powerful magnet (10)

Setting up the Oscilloscope

- Shortcut Method to obtain a trace on the machine.
  1. Turn the machine off.
  2. Turn all knobs with a CAL or AUTO setting to CAL or AUTO.
  3. Turn all other knobs to the mid position.
  4. Turn the brightness knob to maximum.
  5. Switch the machine on and WAIT for about 20secs to 1 minute as most machines need time to warm up.
  6. If the trace does not appear as a straight green line or a moving spot, follow the detailed setup instructions below.
- Detailed Method to obtain a trace.
  1. Identify the POWER switch, often coupled with the brightness control and turn it OFF.
  2. Turn the FOCUS control to the mid-way position.
  3. Rotate the TIME-BASE selector switch (coarse control) to a suitable setting. This adjusts the time taken for the spot to move 1 cm across the screen. The frequency of the waveform will be the reciprocal of the time taken for one complete cycle. For a 50 Hz signal from a power pack choose the 5ms/cm setting on the TIME-BASE Selector so that 1 cycle will take 20ms and cover 4cm of the screen. Only select EXT or HOR INPUT when you are feeding in a signal to the horizontal axis as well as the vertical axis.
  4. Rotate the fine control TIME-BASE knob to CAL (calibrated) which is necessary if accurate voltage readings are to be taken from the screen.
  5. Set the DC/AC switch to DC and leave it there. (AC is only used when trying to view the small varying component of a DC voltage)
  6. Turn the X-SHIFT and Y-SHIFT knobs to the mid-position.
  7. Switch the X-GAIN to the CAL (calibrated) position.
  8. Adjust the Y-GAIN to a mid-way setting such as 1 V/cm.
  9. Set the TRIG level to the auto position.
  10. Set the TRIGGER +/- switch to the + position and set the TRIGGER source to the input selected for use; CH1 or CH2.
  11. Turn ON the power and allow for a 2 minute warm-up period.
  12. Rotate the BRIGHTNESS control to a maximum.
  13. Adjust the STABILITY control so that the trace just starts to appear on the screen.
- Further Setting up Procedure
  - Connect the voltage to be measured by the CRO to the Y-INPUT (VERT INPUT) consisting of 2 sockets, the lower one of which is earthed (—).
  - In order to connect a microphone directly to the Y-INPUT terminals, wrap a short piece of wire around the 'live' end of the microphone plug and connect it to the upper, positive terminal of the CRO. Connect a second piece of wire from the external casing of the plug to the earth input terminal of the CRO (*see figure 1*).
  - When connecting a DC power supply to the Y-INPUT of the CRO **always connect the** *negative* **terminal of the** power source to the *earth* input socket of the CRO.

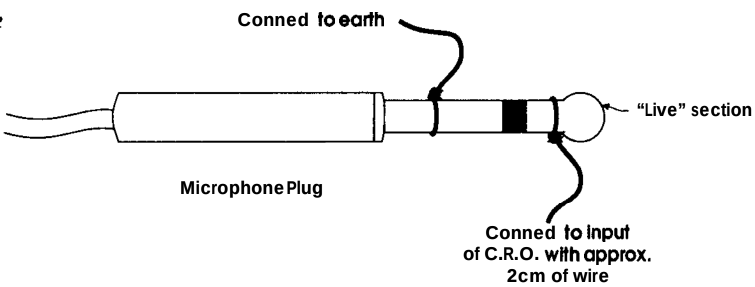


figure I

HANDY HINT

- In order for all students to see the small CRO screen set up the video camera focusing on the trace and connect it up directly to a TV screen. (***See notes on using a video, page 52).***
- Once the machine is turned on leave it on and avoid switching it on and off.

AN OSCILLOSCOPE GLOSSARY

There are many different types of Cathode Ray Oscilloscopes used in schools. Although the principles are the same. the labels on the controls differ. Some of the alternative terms are set out below.

Alternative LABELS on the Control	SETTINGS on the Control	FUNCTION of the Control
Controls for Moving the Spot Across the Screen		
TIME-BASE TIME/DIV TIME/CM	fine control variable control CAL = Calibrated (to read accurately from the screen)	controls the speed of the spot across the screen in s/cm, ms/cm or µs/cm
Controls For Releasing The Spot		
TRIG TRIGGER SWEEP	AUTO - trace always triggers NORMAL (AUTO OFF) - trace only triggers if level is correctly set and signal large enough	controls the release of the spot for each pass across the screen
TRIG LEVEL LEVEL		sets the starting level of the spot
COUPLING	DC - used for most experiences AC - blocks DC signal and lets you see a small AC ripple	
SOURCE	INTERNAL, CH 1, CH2 - looks at the signal on channel 1 or 2 EXTERNAL (EXT) - looks at external input LINE - 240V power line - useful when you want triggering at 50 Hz	causes the trigger to look for a signal
Control for moving the Spot Horizontally		
X POSITION ⇔ POSITION		controls the horizontal position of the whole image
Controls for Moving the Spot Vertically		
VERTICAL AMPLIFIER VOLTS/DIV VOLTS/CM	CAL = calibrated to read accurately voltages from the screen	controls height of the image in volts/cm
Y - POSITION ⇕ - POSITION		controls vertical position of the image

SUGGESTED LEARNING EXPERIENCES

TOPIC: Electricity

1. Investigate the nature of AC and DC voltages. To demonstrate DC, connect a 1.5V dry cell to the Y-INPUT terminals of the CRO. Adjust the Y-GAIN to 0.2V/cm and the TIME-BASE Selector to 1s/cm. To demonstrate AC, connect the demonstration electric generator to the Y-INPUT terminals of the CRO. Set the Y-GAIN on 5 V/cm and the TIME-BASE Selector on 100ms/cm. Note the waveforms and amplitude.

2. **Investigate both the AC and DC voltage outputs from a school power supply.** Connect the AC terminals of a Power pack unit to the Y-INPUT terminals of the CRO and adjust the setting to 'B'. Set the Y-GAIN on 2 V/cm and the TIME-BASE Selector on 10ms/cm. Switch to the DC terminals of the power pack and observe that the so-called DC current is really rectified AC - it is not a smooth consistent voltage output but contains a ripple effect.

TOPIC: Waves

3. **Investigate the properties of periodic sound waves.** Connect a microphone to the Y-INPUT sockets of the CRO as described in the setting up procedure. Set the Y-GAIN to 0.1 V/cm and the TIME-BASE Selector to 1ms/cm. Experiment with speech patterns, whistling, tuning fork, organ pipe, guitar and other musical instruments. Discover the relationship between pitch, frequency and wavelength, and also between loudness and the amplitude of the wave.

4. **Radio wave reception.** Connect a 1 metre long aerial wire to the Y-INPUT terminals of the CRO. Set the Y-GAIN to 0.1 V/cm and the TIME-BASE Selector to 10ms/cm. Measure the frequency of the main component of the electromagnetic radiation and suggest a source for this. Switch the TIME-BASE Selector to 1 s/cm, adjust the stability control and measure the frequency of one of the components now apparent.

5. **Discover the sensitivity of the human ear.** Connect the audio oscillator/amplifier to the Y-INPUT terminals of the CRO. Start with a low frequency and gradually increase the pitch, showing the changing pattern on the screen, until the sound can no longer be heard. The CRO clearly demonstrates the production of a sound. Discuss.

6. **Demonstrate the superposition of waves.** Connect the AC terminals of 2 power pack units in series to the Y-INPUT terminals of the CRO. Set the output from each power pack at setting 'A' (2 volts), the TIME-BASE Selector on the CRO to 10ms/cm and the Y-GAIN control to 2V/cm. *(For further details see page 29 in the Year 12 Senior Physics Prac Manual*)

7. **Demonstrate the nature of standing waves in an open organ pipe.** Connect a microphone directly to the Y-INPUT terminals of the CRO as described in the setting up procedure. Place a small loudspeaker connected to an audio oscillator at one end of the open pipe and the microphone at the other. Starting with a low frequency, increase the pitch of the oscillator till you locate the fundamental for the tube (the lowest frequency which will cause a standing wave pattern in the pipe). Continue increasing the frequency till harmonics are heard and at this point move the microphone along the length of the tube, observing the nodes and antinodes.

8. **Demonstrate the phenomenon of beats.** Connect the DC terminals of a power pack and HI output terminals of an audio oscillator in series to the Y-INPUT terminals of the CRO. Adjust the Y-GAIN control to 2 V/cm and the TIME-BASE Selector to 10ms/cm. Adjust the audio oscillator to almost 50 Hz and observe the characteristic pattern of the beats.

9. **Demonstrate the Lissajous figures** to see the effect produced by a particle subjected to simultaneous periodic motions at right angles to each other. To do this, connect the audio oscillator powered by a transformer, to the Y-INPUT as before. Connect a power pack to the X-INPUT (sometimes located at the back of the machine). Switch the TIME-BASE Selector to EXT or HOR INPUT. Set the Y-GAIN at 2 V/cm. *(Forfurther details see page 34 in the Year 12 Senior Physics Prac Manual*)

Topic - Electromagnetism

10. Demonstrate the production of an induced *emf* in a solenoid. Connect an air-core solenoid, such as the one used in the current balance kit, to the Y-INPUT terminals of the CRO. Adjust the Y-GAIN control to 0.01 V/cm and the TIME-BASE Selector to 1 s/cm for maximum sensitivity. Move a powerful magnet into the centre of the solenoid and note the effect on the screen. Experiment with different types of relative movement of the magnet and the coil.

CLOUD CHAMBER

The cloud chamber is a device that is used to observe directly the products of radioactive decay. In particular, it is exceptionally good for observing the path of α particles. As the radio-active particles travel through the chamber they ionise the atoms in their path. The dipolar vapour molecules surround each of these ions to form a visible droplet path.

There are several different cloud chambers two of which are shown in the photograph. They all consist of two main parts, the top section being the actual cloud chamber where radioactive particle tracks can be observed. The bottom section provides the cooling mechanism which may consist of a second chamber for dry ice, a stem of metal which rests in a vacuum flask filled with dry ice, or a large spring which holds the dry ice in contact with the chamber.

The cloud chamber is very simple to use. Safety precautions should be observed.

SAFETY PRECAUTIONS

- Radioactive sources should *not* be handled with bare hands. Thick leather gloves must be worn or the sources handled with tongs or forceps.
- Wash hands thoroughly after using any radioactive sources ((z-particles do not penetrate the skin but are dangerous if ingested).
- Sources should be clearly labelled and properly stored in a 6mm thick sealed lead container.
- All experimental work should be carried out at a safe working distance of at least 3Ocm.
- Replacement of school sources every 10 years is recommended.
- Avoid touching the dry ice with your fingers by using thick leather gloves.

SETTING UP AND USING THE CLOUD CHAMBER

C **It is worth checking the following items before an experiment is set up:**

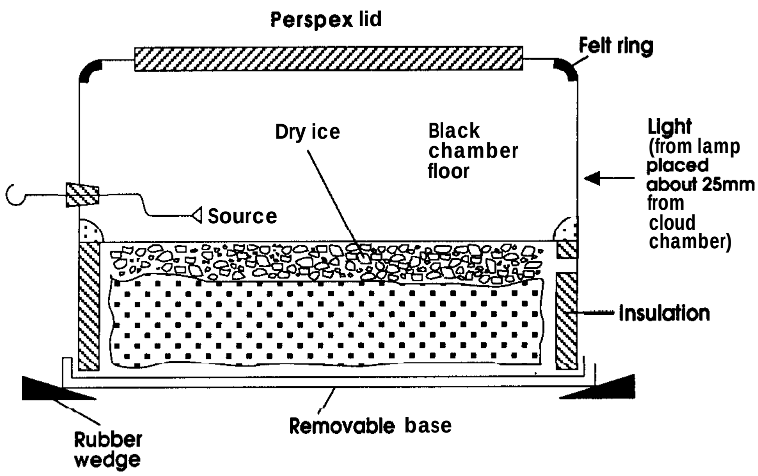
- Ensure that the base is black - in some models the black paint on the bottom tends to peel off. If necessary repaint the surface with hobby enamel paint and allow to dry.
- Ensure that dry ice has been ordered for the required time. Dry ice will last a maximum of 2 days in an ordinary freezer. It can be purchased from the warehouses of the major ice-cream manufacturers. Some companies will also deliver a block of dry ice to the school, providing they already supply the school canteen.

X **Extra equipment for the suggested learning experiences includes:**

- a block of dry ice
- hammer
- flannel cloth
- gloves or tongs to handle the dry ice
- alcohol and dropper
- power pack

- 2 leads
- a small globe for use as a light source which does not create too much heat (some models have them built in)
- radioactive sources mounted on a small metal probe (available from ANSTO) - not the type encased in perspex

S Setting up the Cloud Chamber



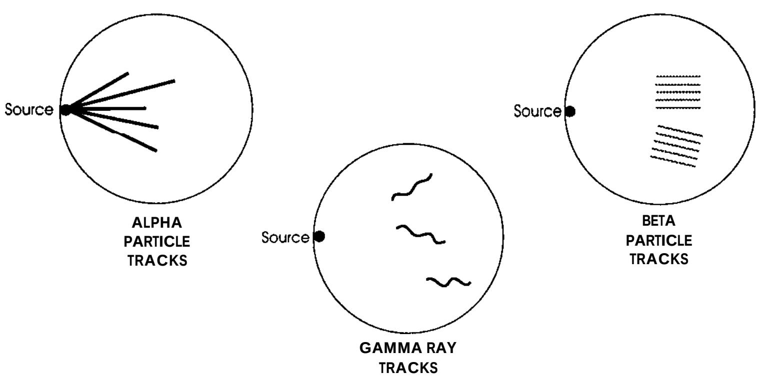
- Place the dry ice between sheets of newspaper and, using a hammer, break the ice into small pieces (notcrushed). Place the dry ice into the lower section of your cloud chamber and set it up to ensure there is maximum surface area contact with the upper chamber.
- Where applicable, place the small rubber wedges under the unit to ensure that it is entirely lifted off the desk and completely level.
- Open the perspex lid of the chamber and soak the sponge/paper ring with alcohol so that the air inside the chamber is super-saturated. If in doubt, use *more* rather than less alcohol. Ensure that one of the rings is at the top of the chamber.
- Replace the lid and *wait* 1-2 minutes.
- Connect the light source to the power supply and turn the light on. The light must be bright but not hot. Position the light so that the chamber is illuminated from the *side*, rather than the top.
- Insert the radioactive source into the small hole in the side of the chamber.
- Repeatedly rub the perspex lid with a flannel cloth in order to give it an electrostatic charge.

HANDY HINT

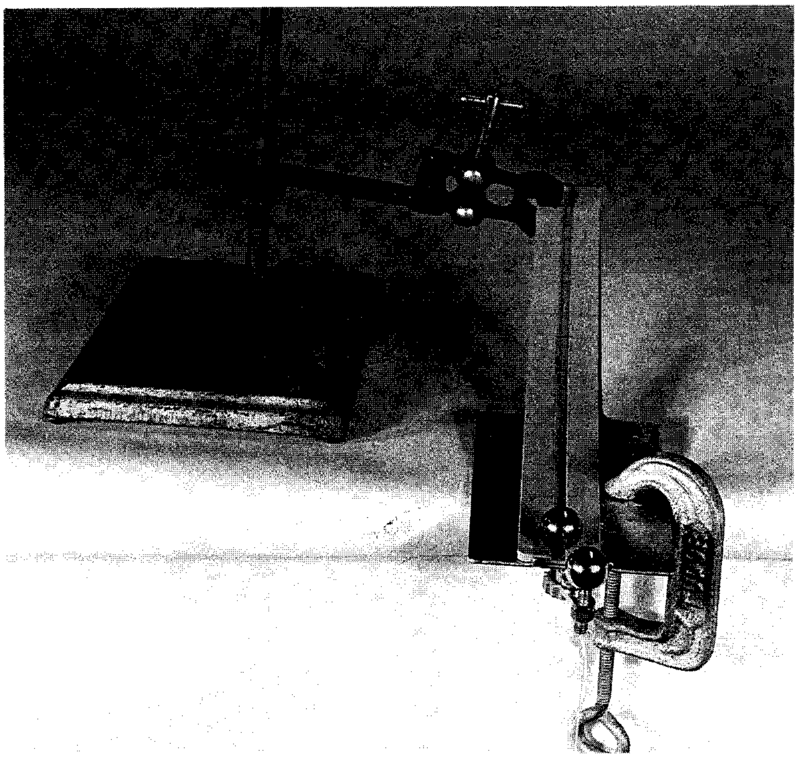
- If the experiment is unsuccessful check the age and activity of your radioactive sources by using a geiger counter.

SUGGESTED LEARNING EXPERIENCES

1. Observe alpha particle tracks as short, shooting lines radiating from an alpha source such as Americium-24 1 (see *below).*
2. Observe the tracks from a beta source such as Strontium-90 or Caesium- 137. These are seen as faint wavelike, parallel lines visible only for a short period of time (see *opposite).*
3. Observe gamma or X-ray tracks from a source such as Cobalt-60. These are seen as very obvious squiggly lines that follow a short, random path (see *opposite).*



COLLISIONS IN TWO DIMENSIONS KIT



This kit enables students to investigate collisions in one and two dimensions thus exploring the conservation of momentum and energy.

There are a number of variations of this kit available, but the essentials are the same. The equipment consists of a curved grooved track, along which a steel ball is allowed to roll.

At the end of the track there is an arm to hold a second ball in a stationary position. This arm can be adjusted to position the ball for a head-on collision or one at a glancing angle. Both balls are launched into a trajectory with the point of impact on the floor being recorded by a piece of carbon on plain paper.

SETTING UP AND USING THE COLLISIONS IN TWO DIMENSIONS KIT

X Extra equipment for the suggested learning experiences includes:

- carbon paper
- large sheets of white paper
- plumb bob and string
- meter rule
- g-clamp
- retort stand, bosshead and clamp
- vernier callipers
- balance to measure the mass of the balls
- protractor
- masking tape
- steel balls (not marbles, as there is a 20% variation in mass)

S Setting up the Collisions in Two Dimensions Kit

- Clamp the curved track to the edge of the bench with a G-clamp so that the lower end extends out from the edge of the bench.

- Fix the upper end of the track in a clamp attached to a retort stand. The clamp should be close to the bench top.
- Hang a plumb bob on the end of a long thread from the set-screw on the adjustable arm at the end of the track, directly below the target ball. For accurate measurement the plumb bob should be poised just above the floor.
- Tape some plain paper to the floor, to cover the area in which the balls are expected to hit. NOTE: To estimate the size of this area, let the ball roll freely down the track and note its position as it hits the floor. Repeat, placing another ball on the adjustable arm and once again note the position at impact with the floor.
- Measure the mass of each of the steel balls. Select two with the same mass and one with a much lighter mass.
- Measure and record the diameter of the steel balls using vernier callipers.
- Set the adjustable arm so that there is a distance of 1.5 times the diameter of the target ball between the centre of the target ball and the end of the track (*see figure 1*).

  NOTE: For some sets of equipment this will require the use of steel balls with a maximum diameter of 13mm.
- Move this bracket to make an angle of approximately 45° with the path of the rolling ball. Fasten the bracket tightly in position.
- Loosen the lock-nut on the adjustable arm and adjust the height of the set-screw on which the target ball sits so that the rolling ball just skims across the top of it. Tighten the lock-nut in place.
- Place a target ball on the adjustable arm at the end of the track.
- Fasten some carbon paper face down on top of the plain paper.

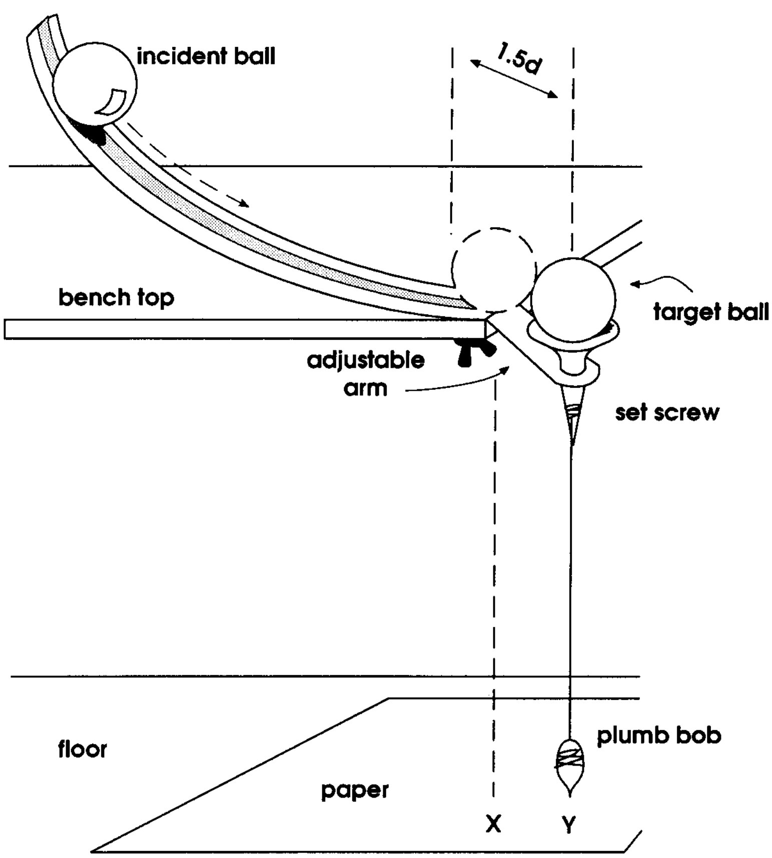


figure 1

HANDY HINT

- To ensure that there is no confusion, mark each point of impact immediately after the event by lifting the carbon and marking the point with a circle and number to indicate the order of events.

SUGGESTED LEARNING EXPERIENCES

The learning experiences require a similar procedure and analysis which is outlined below.

Procedure

- Mark the position of the plumb bob clearly on the paper directly below the centre of the target ball *('Y' in figure 1)*
- Measure accurately and record on the paper the point directly below the centre of the rolling ball at the time of impact *('X' in figure 1).*
- Experiment to find a suitable position from which to release the rolling ball (approx. 25 cm). Mark this position clearly on the ruler and always release from the same point being careful not to push the ball so that the acceleration is only due to gravity.
- Release the ball from this point several times and mark the spot clearly on the paper where it hits the floor.
- Set up another steel ball on the adjustable arm and proceed with the specific collision required.
- Take an average of at least five readings when collecting results.
- Connect the initial and final points of impact for each ball on the paper with straight lines and measure their length.

Analysis

To alleviate confusion about the quantities actually being measured, students should be made aware of the following:
Since the balls are released in a trajectory motion, their horizontal velocity will be constant, while they accelerate vertically to the floor under the force of gravity (assuming air resistance is minimal). As the time taken to reach the floor is the same for each ball under gravity, then the displacement of each ball is directly proportional to its horizontal velocity. (**d=v.t**) Hence measuring the displacements of the steel balls provides a *proportionate* measure of their velocities (not the actual velocities) in the horizontal plane. If the masses of the balls are the same, the displacement vectors can be compared directly to demonstrate conservation of momentum.

TOPIC - Collisions

1. **Verify the conservation of momentum in a 2-dimensional collision** using identical balls set at an angle of approximately 45°. Draw the displacement vectors of both balls after the collision on the paper, adding them vectorially, head to tail. Compare this with the displacement vector of the incident ball when there is no target ball to hit. Discuss sources of error.

   Repeat the collision using different angles.

   Repeat the collision using a lighter ball as the target ball. (In this case momentum vectors will have to be drawn taking into account the difference in mass.)

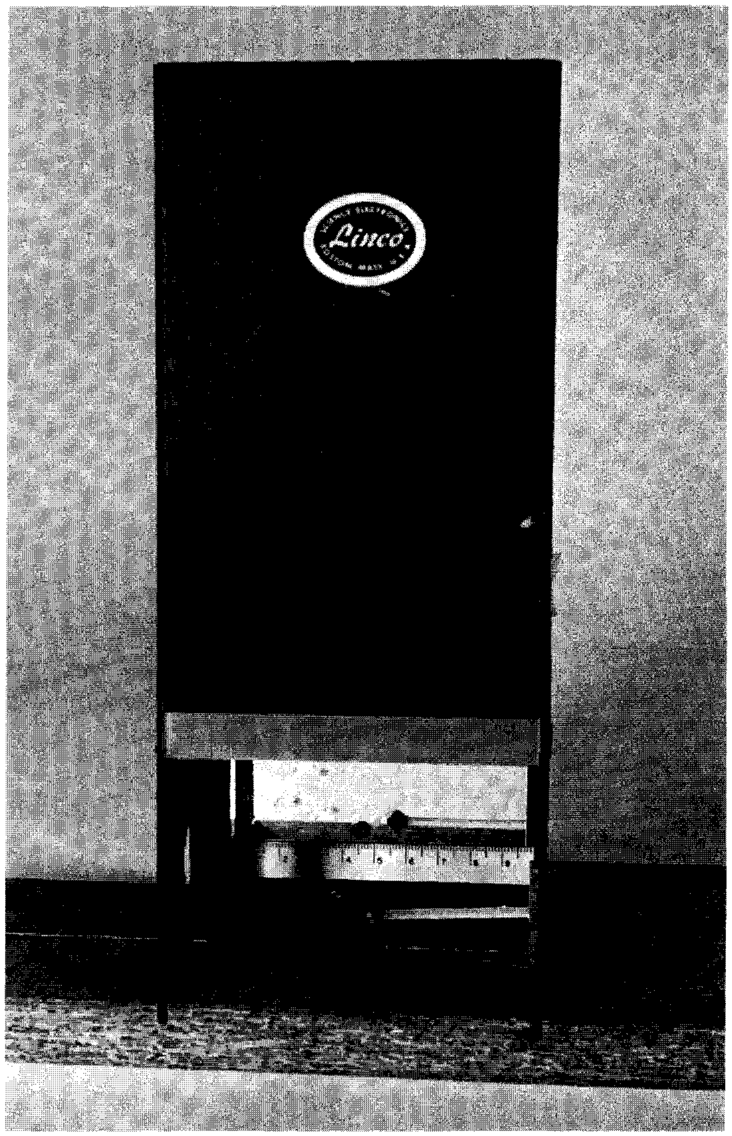
2. **Investigate the conservation of kinetic energy using similar conditions for a 2-dimensional collision as in part 1.** To compare kinetic energy, square the magnitudes of the displacements and simply add them as kinetic energy is not a vector quantity.

3. **Verify the conservation of momentum for a head-on 1-dimensional collision**, being very careful to align exactly the centres of the colliding balls.
   Repeat the collision using balls of different masses.

4. **Investigate the conservation of kinetic energy in a 1-dimensional collision.**
   For more information, see the PSSC manual p51, or Essential Physics, page 76.

COULOMB'S LAW

The Coulomb's Law Kit is designed to investigate the electrostatic force between charged pith balls in a protected environment inside a black box.



The pith balls can be charged using an electrophorus, a perspex rod or acetate strips.

The box contains a window for viewing the interactions, a scale for taking measurements and a mirror mounted to enable accurate readings to be taken.

SETTING UP AND USING COULOMB'S LAW KIT

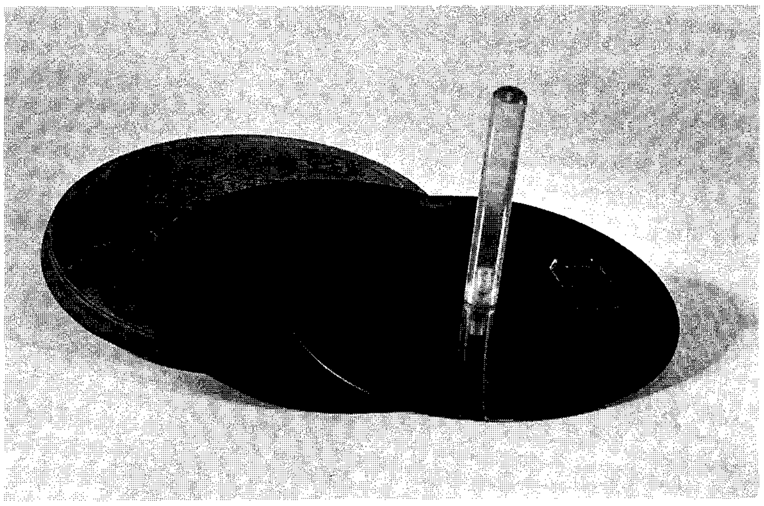
It is worth noting the following before setting up the equipment.

- *This equipment is heavily dependent on the weather conditions.* The electrostatic charge leaks away rapidly to water molecules and dust particles in the air. Hence the equipment works well on a dry windy day but poorly on a wet, humid day.
- Check that there are metallic-coated pith balls with the equipment.
- Check that a ball is stuck firmly to each of the plastic rods protruding from the sliding wooden stands.
- Keep all the charged objects (pith balls, electrophorus, rods) away from good conductors such as metals which will discharge them.

Extra equipment for the suggested learning experiences includes:

- electrophorus and flannel or . . .
- perspex rod and silk
- silk thread (less kinky than the nylon thread supplied)
- a scalpel to pierce the pith ball so that it can hang on the silk thread
- aluminium powder or graphite to coat the pith balls
- an overhead projector
- large sheets of paper to put on the wall
- an overhead transparency made from graph paper.

- Position the black box and lid on the overhead projector and leave for approximately half an hour before doing the experiments as the heat from the projector helps to dry out the air, improving the results.
- Use a scalpel to cut a slit in one of the pith balls and thread it on to a piece of silk thread. Remove any kinks from the thread so that the movement of the suspended ball, as far as possible, is restricted to one dimension.
- Dip the metallic-coated pith balls in aluminium powder or graphite to enhance the amount of charge they can sustain.
- Suspend this thread by attaching it through the small slits cut into opposite sides of the top of the box to form a V-shape.
- Adjust the pith ball so that it hangs in the middle of the viewing area in front of the mirror approximately centred on the scale markings and level with the fixed ball attached to the wooden block.
- *Charge the pith balls using one of the following methods*



The Electrophorus

1. On a good day (low humidity) it is easier to use a *perspex rod and silk cloth* to charge the pith balls. Vigorously rub the perspex rod with silk and touch the pith balls by inserting the rod through the side of the box.
2. For a larger charge or for use on a humid day, try the *electrophorus*. Induce a charge on the upper metal disc of the electrophorus in the following way:
   - Use a flannel cloth to rub vigorously the ebonite disc of the electrophorus.
   - Place the metal disc on top and earth it by touching the top of it with your finger.
   - Remove your finger first and then the metal disc, being careful to keep it exactly horizontal as you lift it off the ebonite. The induced charge will remain on the disc of the electrophorus for longer than that on the perspex rod.
   - Lift the suspended pith ball out of the box to touch it with the metal disc.
   - Ensure that the pith ball does not touch the sides of the box after it has been charged.

HANDY HINTS

- Position the whole apparatus at eye-level for taking measurements.
- Readings must be taken within 30 seconds to ensure the minimum charge leakage.
- Test the amount of leakage by returning the balls to the initial separation and record the deviation once again. The difference between these readings will give a measure of the amount of charge which has leaked into the air (use this for error calculations).
- Charge both pith balls with the same charge as it is easier to manage the repulsive force between like charges than it is to control the attractive force between oppositely charged objects.
- When taking measurements, cover the box with the perspex lid and one side of the box with cardboard to prevent any currents of air from blowing the suspended ball.
- When taking measurements using the ruler and mirror, line up the pith ball with its image in the mirror to prevent parallax error.
- The experiences can all be performed on the overhead projector and consecutive positions marked on the image which has been projected onto the blackboard or large pieces of paper taped to the wall.

TOPIC: Electrostatics

1. **Discover the mathematical dependence of the electrostatic force (F_E) between two charged objects and the distance (r) separating them. [F_E a $1/r^2$]** ***This experiment is written up in many texts, including the PSSC Laboratory Manual, page 63.***

   This is a quantitative experiment involving the measurement of two distances. The distance r is between the pith balls and d is the distance the suspended pith ball moves from its equilibrium position. This second distance is shown in figure 1 to be a measure of the electrostatic force when both pith balls are charged.

   As the fixed ball is moved closer to the suspended ball, pairs of measurements are quickly taken. To avoid too much error from the leakage of charge to the air, each set of measurements should be taken in a 30 second period. Graphs of **F_E (d)** against r, r^2 and $1/r^2$ can be obtained from the results.

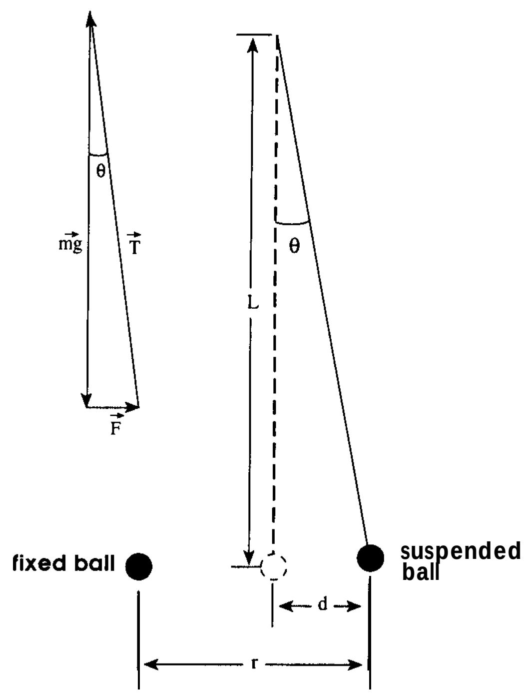


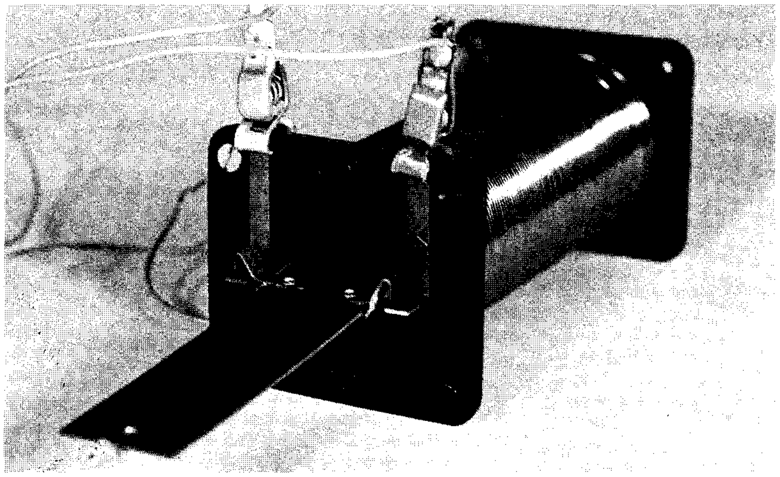
figure 1

2. Investigate the relationship between the **electrostatic force on two charged objects and the charge on each of them. [$F_E \alpha q_1 q_2$]**
   This is a quantitative experiment involving the measurement of the deflection of the suspended pith ball at a fixed distance from another charged ball (a measure of the electrostatic force) while varying the charge on one of the balls.
   - Note the equilibrium position of the suspended ball.
   - Charge both balls with the same charged rod or electrophorus.
   - Select a position for the fixed ball which produces a strong deflection in the suspended ball.
   - Halve the charge on the suspended ball by touching it with an identical, neutrally charged ball.
   - Note the new position of the suspended ball.
   - Repeat the procedure, halving the charge of the suspended ball again, though all measurements for a particular original charging should be taken within a 30 second period to avoid charge leakage into the air.
   - The whole experiment can be repeated several times.
   - As an extension to this experiment, halve the charge on both the pith balls and record the effect on the electrostatic force between them.

3. **Demonstrate the vector addition of electrostatic forces on a charged object.**
   See ***page*** 67 of ***the PSSC Laboratory Manual for details of the procedure.***
   This is a quantitative experiment involving the measurement of the deflection of the suspended ball when two similarly charged balls are placed close to it.
   In order to measure the direction of the deflection the pith ball must be suspended by one single thread from the centre of the perspex lid of the box.
   This experiment is easier to see if the whole thing is done on the overhead projector. Make an overhead transparency of the graph paper supplied and place it underneath the box. Measurements can be made on a piece of paper taped to the wall on to which the experimental grid has been projected.

CURRENT BALANCE KIT

The current balance kit is used to demonstrate the effect of a magnetic force on a current-carrying wire and to use this effect to measure the strength of the magnetic field at the centre of a solenoid.



The kit consists of a loop of wire mounted on one end of a rectangular armature. The armature is balanced on pivotal contacts at one end of a solenoid so that the loop of wire sits inside it.

When a current of electricity flows through the solenoid and also through the loop of wire, ***the armature moves,*** revealing a force between them.

SAFETY PRECAUTION

Do not use a current of over 5 amps in the solenoid, as this will damage the contacts.

SETTING UP AND USING THE CURRENT BALANCE KIT

C **It is worth checking the following items before an experiment is set up**

- Although there are several models of this apparatus, these differ mainly in the type of contacts used as the pivot. It is important to check how the contact is made to ensure the free movement of the armature and maximum flow of current.
- Clean the contacts with 200 wet/dry sandpaper, glass paper or an emery board.

X **Extra equipment for the suggested learning experiences includes:**

- 2 ammeters
- 8 leads
- 2 rheostats
- 1 balance to measure the mass of the string

Setting up the Current Balance Kit

- Attach the metal strips/contacts to one end of the plastic cheek of the solenoid using the alligator clips. The contacts should slide into ready-made grooves in the outside of the cheek with the clips protruding from either side of the hole in the solenoid for the pivot points of the armature to swing freely on them (***see figure 1)*** Put the armature in place, balancing on its pivoting points.

- Set up the rest of the circuit following the circuit diagram in *figure* 2. NOTE: The balance should move when both circuits are turned on and the current is adjusted to approximately 4 amps, using the rheostats.

- If the readings on the ammeters are fluctuating clean the contacts again.

- If the currents cannot be varied, then see the Handy Hints section below on connecting the rheostats.

- **With NO current flowing in the circuit,** balance the armature to the horizontal by adjusting the screw on the end of the armature which is outside the solenoid.

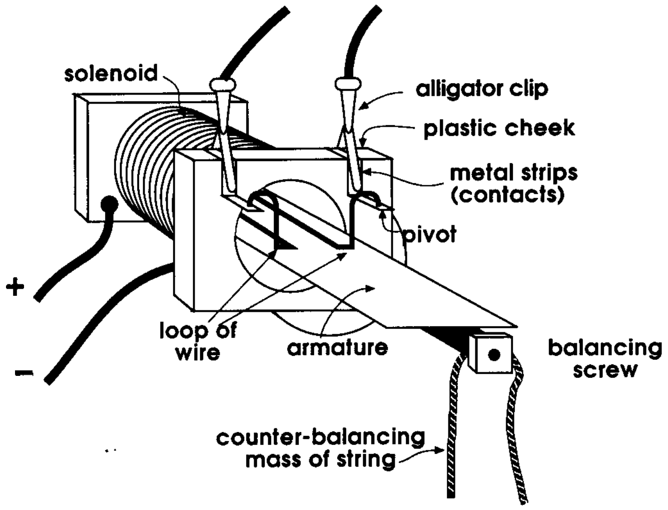


figure 1

HANDY HINTS

- For models where the armature has a printed circuit with a loop of conducting material each side of the central pivoting points, you will need to determine which end of the armature will complete the circuit. This is easily achieved by locating small breaks in the circuit on one side of the pivot points. As this loop is broken, it will not complete the circuit. It is only present to balance the armature. The *other* side consists of the unbroken circuit loop through which the current will flow. Place t*unbroken* circuit inside the centre of the solenoid, balancing the pivot points on the metal contacts.

- *To connect a rheostat* into a circuit correctly, you must connect one lead to the thick top bar and the other lead to the bottom coil at the other end of the rheostat (*see figure* 3). The current will then flow from the bottom contact, through the coil to the sliding connector and across the thick bar at the top of the rheostat. The current flowing through the circuit can be adjusted by moving the sliding connector.

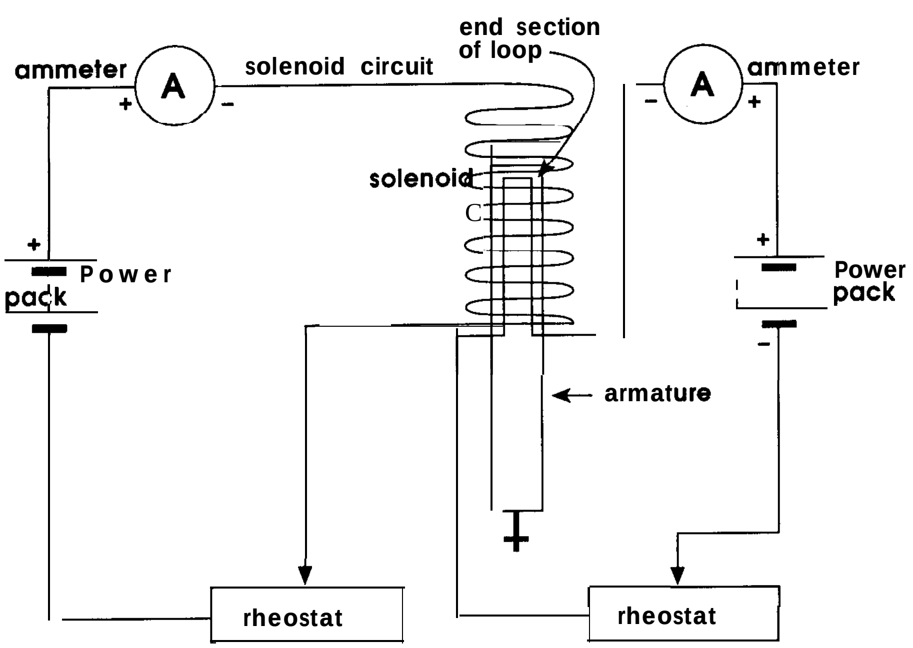
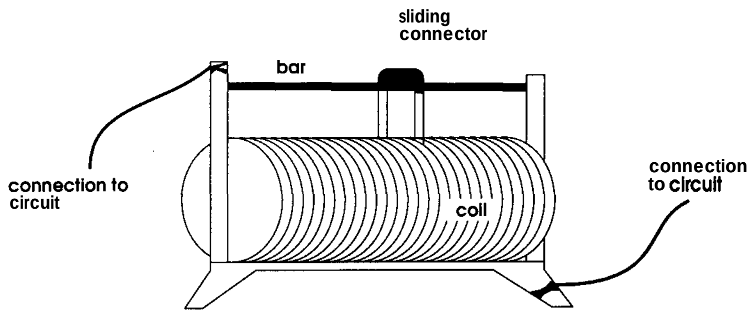


figure 2

SUGGESTED LEARNING EXPERIENCES

1. **Discover qualitatively the force exerted on a current-carrying wire in a magnetic field.** Set up the balance andcompare the effect' on the armature of varying the current in the solenoid from a minimum to a maximum . Vary the current in the loop and compare the effects on the armature. Ask the students to form some general statements explaining what they have experienced.



Rheostat

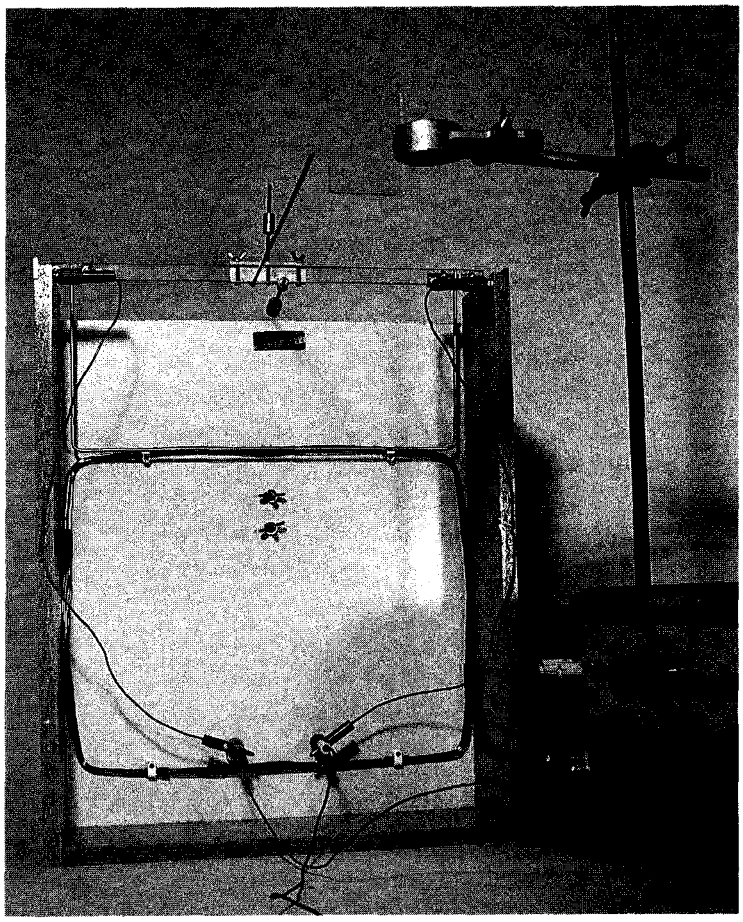
figure 3

2. **Calculate the magnetic field intensity (B) at the centre of the solenoid,** by measuring the force exerted on the end of a rectangular current-carrying loop of wire. (The small piece of wire across the very end of the armature, positioned in the solenoid, is the only part of the loop which is actually affected by the magnetic field as it is at right-angles to the field. The other two sides of the loop are parallel to the magnetic field, inside the solenoid, and will not be affected).

   - Use the equation **$F = B I l \sin\theta$** where $\theta = 90°$ and $l \cong$ 3cm *(the length of the wire across the end of the armature).*
   - Turn on the power and observe the internal section of the armature pushed down by the magnetic force between the loop and the solenoid.
   - Measure this magnetic force **(F)** by placing short lengths of string as counter-balancing weights on the other end of the armature until it is balanced in the horizontal position.
   - Make sure that the string is placed at an equal distance from the pivoting points when compared with the end section of the loop affected by the magnetic field inside the solenoid.
   - The mass of the string is measured on a balance. Alternatively, measure the mass of a known length of string and calculate its mass/cm. Then, measure the length of string required to balance the armature and calculate its mass.
   - To give the force **(F)** in newtons, multiply the mass in kilograms by 9.8
   - Set the current in the solenoid to 4 amps and calculate the force (F) required to balance different values of current (I) in the loop.
   - Vary I using the rheostat and plot a graph of F against I. (The gradient of the graph will be a measure of **$B.l$**). Hence calculate B. See *the PSSC Manual p77 for further details.*

3. **The solenoid from the current balance kit is used in conjunction with the Mass of the Electron apparatus - see** *page* 36.

CURRENT BALANCE



The current balance is used effectively to investigate the magnetic force between 2 current-carrying wires. It consists of a wooden structure holding a fixed square loop of wire and a balancing armature to hold another loop of wire at varying distances from the fixed one. When these two loops are connected in two separate circuits and the current in each circuit turned on, the armature including the single loop is caused to move. The distance moved is a measure of the magnetic force between the loops.

SAFETY PRECAUTIONS

Take care when handling the perspex armature as it is easily broken about the central point.

SETTING UP AND USING THE CURRENT BALANCE

C **It is worth checking the following items before an experiment is set up**

- Ensure that the wire loops have straight sides.
- Since this equipment is a sensitive balance, choose a solid base on which to set it up and shield it from a draught.

X **Extra equipment for the suggested learning experiences includes:**

- 2 power packs
- Retort stand, bosshead and clamp
- 4 red leads and 4 yellow leads
- vernier callipers
- wire cutters
- 2 rheostats
- 2 DC ammeters (0-5 Amps)
- thin wire to make a small counter balance
- a ruler

S **Setting up the Current Balance**

- Using figures 1 and 2 assemble the armature fittings as follows:
  Loosen the wingnuts (N) under the centre of the armature and insert the pointer(P) into one of the slots so that the first notch (zero mark) is aligned with the knife edges. Insert the counter mass (M) into the other slot so that it protrudes on the opposite side of the beam from the pointer. Tighten the wingnuts. Insert the sensitivity adjustment rod with masses (A) into the hole in the centre of the beam balance.

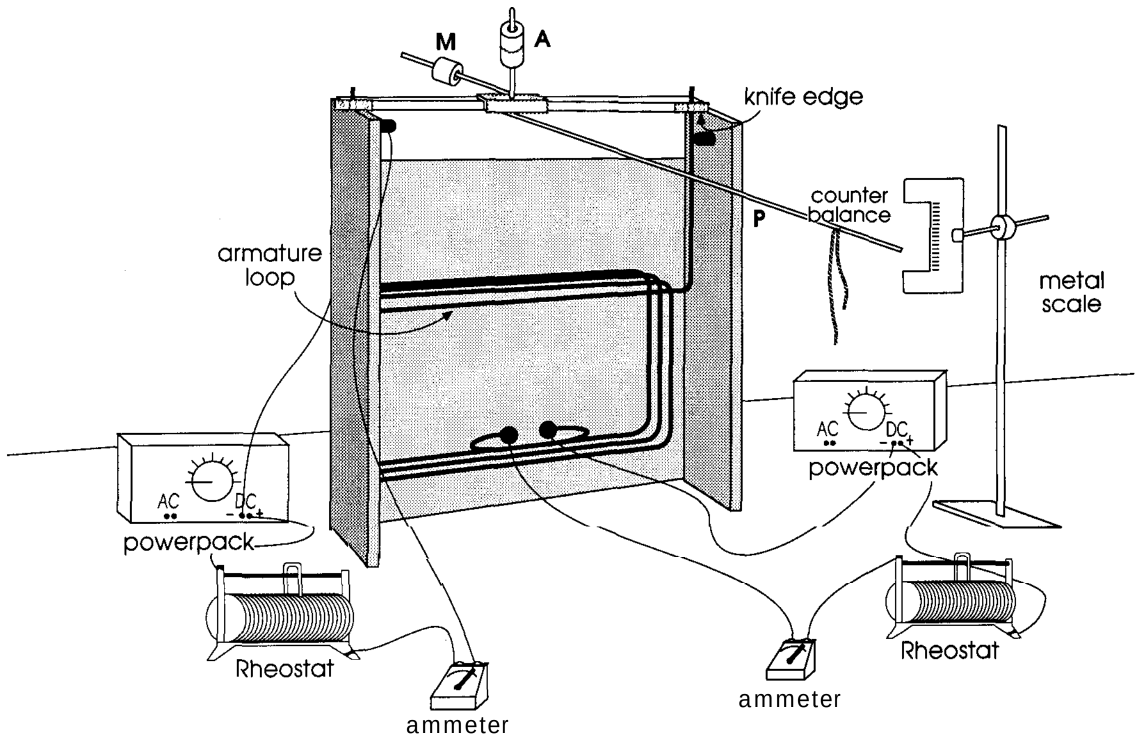


figure 1

Loosen the wingnuts (S) on either side of the armature and insert the longest loop into the slots near the wingnuts. Allow 2 mm of each end of the loop to protrude above the beam. Tighten the wingnuts.

- Place the beam so that the knife edges are located in the 2 'V' slots outermost from the fixed loop.
- Fix the zero marker in a clamp mounted on a retort stand and position it so that the pointer can oscillate only between the inner faces of the zero marker.
- Check that the pointer is free to oscillate.
- Adjust the balance using the following steps:
  1. Lower the sensitivity mass A and the counter mass M until the suspended wire is exactly vertically balanced. To ensure this, measure the distances between the tops of the fixed and movable loops and the bottoms of the fixed and moveable loops. If these distances are equal, the loop is vertical.
  2. Set the zero marker, by moving it up or down on the retort stand, so that the pointer is exactly at zero. To avoid parallax error, the small metal ruler may be used as a mirror to line up the pointer and its image.
- Connect the 2 separate circuits as indicated in figure 3.
- To help clarify the complicated setup, use a set of different coloured wires for each circuit.

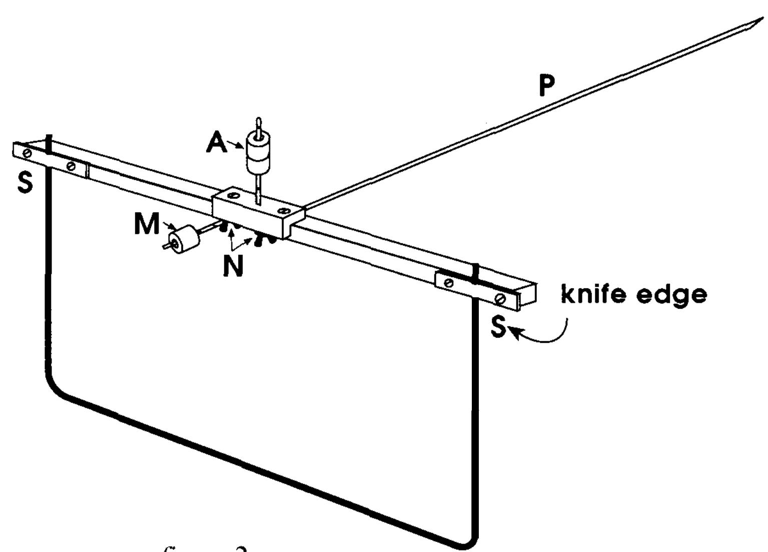


figure 2

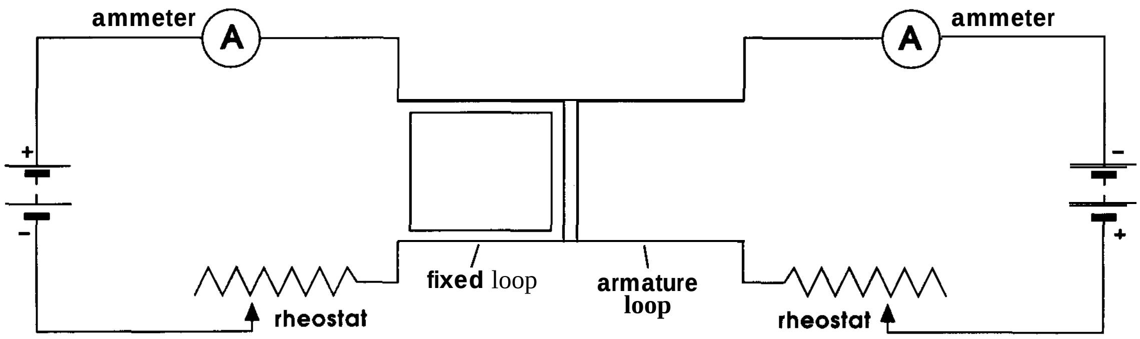


figure 3

HANDY HINT

If you no longer have the small counter balance, use 15 mm of a paper clip bent into an 's' shape to hang on the pointer.

SUGGESTED LEARNING EXPERIENCES

This equipment shows very clearly the phenomenon of the magnetic force between two current-carrying wires. It can be used to demonstrate *qualitatively* the dependence of the force on the direction and magnitude of the currents, the distance between the wires and common length of the wires. To obtain *quantitative* verification of the relationship takes patience as the armature must be balanced each time. However the results obtained are generally good.

The following is an outline of the general procedure required to balance the loop, in order to take measurements of the force between the wires:

- Set up the balance as described above, adjusting the balance to read zero on the scale with no current flowing in the circuits.
- Adjust the current flowing in the wires, using the rheostats so that *at least 4 amps* is flowing in each circuit. ***(If you cannot adjust the current using the rheostats, see note on connecting rheostats in the section on Hundy Hints on puge 22).***
- Balance the armature by suspending a small counter-balancing mass (see ***Handy Hint above***) in one of the slots on the pointer. Measure the distance from the pivoting point to the counter-balancing mass. This distance **(d)** is proportional to the force **(F)** between the wires,

as $\mathbf{F \propto mgd}$ where **m**=mass of the counter balance (kg), **g**=9.8 ms^{-2}.

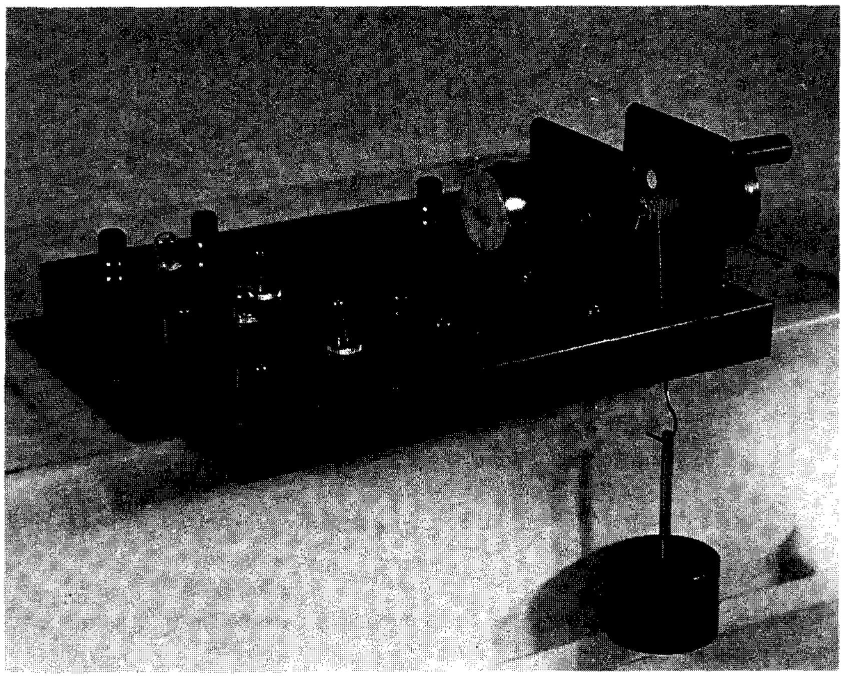
1. **Qualitative investigation of attractive and repulsive forces between current-carrying wires.**

2. **Verify the dependence of the force between the wires and the current in each wire,** as given by the expression $\mathbf{F \propto I_1 I_2}$ In this case, it is physically easier to place the counter-balancing mass at regular intervals, say 2 cm apart, and adjust the current in the loop to balance the pointer. (See ***Yeur 12 Senior Physics Pruc manual for details***)

3. **Verify the relationship between the magnitude of the force on the wires and the distance between them,** given by the expression $\mathbf{F \propto l/d}$. Adjust the distance between the wires by placing the armature in different positions on the knife edges. (See ***Yeur 12 Senior Physics Pruc manual for details***)

4. **Verify that the force between two current-carrying wires depends on the length of wire common to both,** given by the expression **F a *l*, by** using loops of different sizes provided in the kit. (See ***Yeur 12 Senior Physics Pruc manual for details***) Note: this investigation is particularly time consuming and difficult to perform, quantitatively.

ENERGY INTERCONVERSION KIT



The Energy Interconversion Kit has been designed to demonstrate the interconversion of gravitational potential energy and electrical energy.

It consists of an electric motor connected to a winch that raises a fixed mass on the end of a string. The motor can be used to drive the winch, or the falling mass used to drive the motor as a generator. Two small globes are used to demonstrate the presence of an electric current.

The kit can vary in construction. In some models a system of gears is used to connect the winch and motor, instead of a belt and pulley.

SETTING UP AND USING THE ENERGY INTERCONVERSION KIT

It is worth checking the following items before an experiment is set up.

- ensure that the electrical connections are secure and make sure the mass is able to fall freely on to the floor
- trace the circuitry on the underside of the board to note which terminals are connected to the motor, lamps, etc. *NOTE: In some models there is a set of disconnected terminals labelled INPUT which cannot be used*
- ensure the bulbs are not blown
- replace the drive belt if it is worn
- tighten the spindle on to the shaft to avoid slipping
- check leads

X **Extra equipment required for the suggested learning experiences includes:**

- electrical leads, including banana plugs
- a voltmeter (0-10V) or multimeter
- a meter rule
- a g-clamp to fasten the board to the desk firmly
- batteries for battery holder or power pack
- a milliammeter (0-500 scale)
- a stopwatch

HANDY HINTS

- Reverse the connections on both the voltmeter and milliammeter when switching from using gravitational potential energy to using electrical energy as the electrical current will be flowing in the opposite direction.
- Be careful to keep the banana plug connectors well away from the metal board so that there is no possibility of a short circuit.
- Wind the cord uniformly on the spindle to minimise energy loss.
- If the power pack is used as a source of electrical energy, try the "B" setting (3 volts).

SUGGESTION FOR USE IN THE CLASSROOM:

This piece of equipment is recommended to be used apart of a series of workstations based on mechanical interactions. With written instructions it is relatively easy for students to use as the underlying concepts are demonstrated quite concretely and the calculations are not overly complicated.

SUGGESTED LEARNING EXPERIENCES

TOPIC: Energy

1. Determining an energy conversion chain.

Demonstrate the interconversion of different types of energy beginning with stored chemical energy in the battery, progressing to gravitational potential energy in the raised mass on the string.

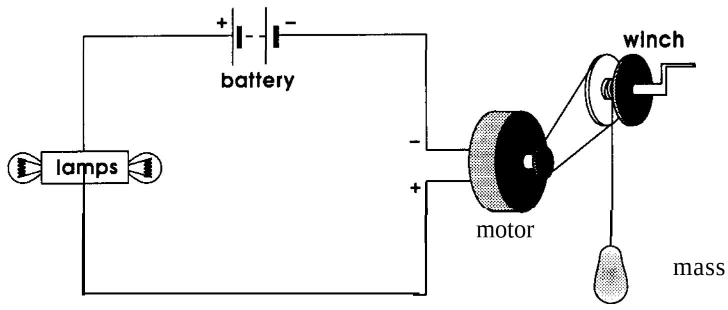


figure 1

To do this:

- Connect one of the 3v battery leads (or the 'B' setting of the power pack) to the input terminal of the motor as shown in figure 1.
- Turn on both switches for the bulbs.
- Attach a mass and carrier to the end of the string so that it is just resting on the floor. Connect the other battery lead and observe the motor pulling the mass up to the bench. Disconnect the battery when the mass reaches the bench.
- Watch as the mass then drives the motor as a generator in the opposite direction, creating an electric current which lights the globes.
- Experiment using a larger mass (masses over 500g are recommended). Ask the students to predict the outcome.
- Repeat the experiment using just one globe and discuss the results.
- Students should produce their answer in the form of a flow chart, indicating in which part of the device each transformation takes place and the possible pathways in which energy is lost.

2. Measure the electrical energy that can be produced by a falling mass.

This experience enables students to measure the amount of electrical energy generated from a known amount of gravitational potential energy and to determine the loss of energy in the process. ***To do this:***

- Connect the circuit as shown in figure 2, being careful to connect the meters so they record a positive deflection when the mass is falling to the ground.
- Wind the string carefully on to the winch and attach the mass and carrier to it.
- Support the mass and release when ready.
- With a meter rule, measure the distance travelled. Be careful not to include the height of the mass.

- Measure the mass of the falling object including the supporting mass carrier.
- Using $g=9.8\ ms^{-2}$, ask the students to calculate the stored energy in the falling mass from the equation

  PE = mgh

- Take several readings of the time (seconds) taken for the mass to hit the floor.

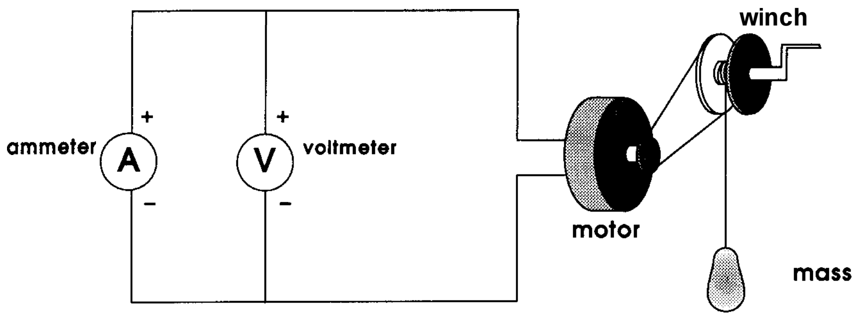


figure 2

- At the same time take readings of the voltage (volts) and current (amps) produced by the motor acting as a generator.
- Using the following equation, ask the students to calculate the electrical energy produced by the generator.

$$\text{WORK} = E_{Electric} = V\ I.t$$

- Compare the two values and determine the amount of energy 'lost' in the transformation. To reinforce the concept of energy conservation discuss where the 'lost' energy has gone (heat, sound).
- Encourage students to estimate their errors in taking measurements and in their calculated results. How does this affect their calculation of the energy lost in the conversion?
- Vary the mass of the object and compare the percentage energy loss in each case.

3. Measure the gravitational potential energy that can be produced by an electric motor.

This experience enables students to measure the gravitational potential energy converted from a known amount of electrical energy and hence to find the efficiency of the motor. ***To do this:***

- Connect the circuit as shown in figure 3 being careful to match the positive terminals of the meters with the positive terminal of the battery (or power pack).
- Position the mass and carrier on the floor immediately below the winch with the string taut.
- Use the device as a motor to raise a fixed load.
- Measure the quantities, as in the previous experiment, to determine the electrical potential energy used and the gravitational potential energy produced in the transformation.
- Calculate the efficiency of the motor by dividing its input energy (VIt) by its output energy (mgh) and multiplying by 100 to give a percentage.

$$\textbf{Efficiency} = \frac{\textbf{VIt x 100}}{\textbf{mgh}}$$

- Vary the mass and compare the results. Does the motor have a standard efficiency rating?

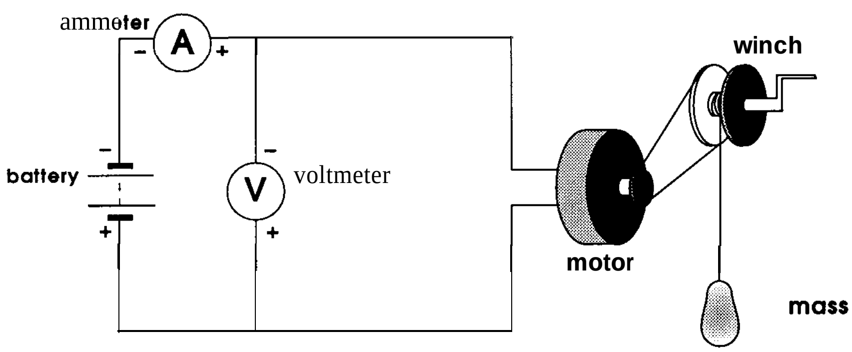


figure 3

GAS DISCHARGE TUBES

This section contains information about the discharge tubes available for use in most school laboratories. It includes the set of three Crooke's tubes, the six tubes for vacuum scale and the spectrum tubes. The induction coil has been included as it provides the high input voltage required to operate the tubes. Although the different discharge tubes are used to demonstrate a variety of principles many of the safety aspects are common.

SAFETY PRECAUTIONS

- The induction coil itself does ***NOT*** produce X-rays. However, X-rays are produced in the discharge tubes when they are connected to the induction coil. The X-rays are emitted when the cathode rays are stopped suddenly by hitting glass or metal surfaces. When the equipment is set up using a *minimum operating voltage* from the induction coil the X-rays produced are of low energy and are significantly attenuated through the glass.
- Remove all metal jewellery and watches before using the induction coil.
- *Keep one hand behind your back when operating the apparatus.* This helps to ensure that you do not provide a short circuit for the high voltage electric current.
- Do not handle the glass tube while it is in operation.
- Do not leave this equipment on for longer than is necessary to perform the desired experiment.

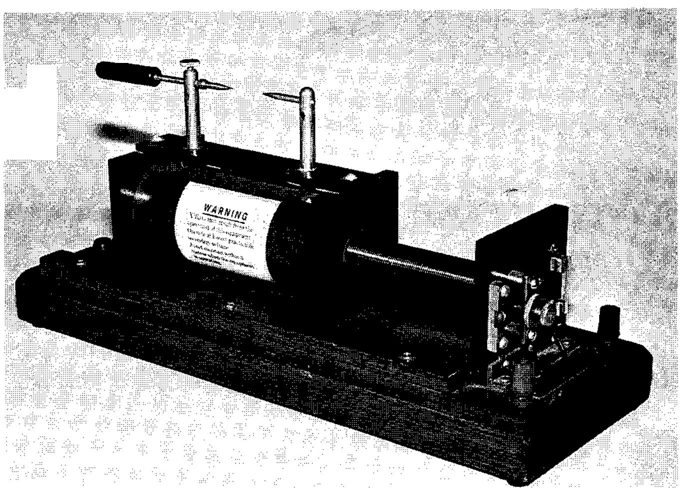
X **Extra equipment for ALL the suggested learning experiences using the discharge tubes includes:**

- induction coil
- two long leads with alligator clips
- power pack
- black cardboard
- two leads with banana plugs
- spare fuses for the induction coil

HANDY HINT

For impressive results, darken the laboratory or set up in a large darkroom.

1) INDUCTION COIL



The induction coil is used as a high voltage power sourcebecause it produces by electro-magnetic induction a very high voltage in its secondary coil. It pulsates a small direct input voltage of 6V in the primary coil to produce a variable output in the order of 15 000 volts in the secondary coil. The two electrodes, mounted on the secondary coil, are used as a high voltage supply.

SETTING UP AND USING THE INDUCTION COIL

C **It is worth checking the following before setting up the equipment.**

- Make sure the contacts are clean and free of carbon deposits. If not, clean them with fine sandpaper.
- Use the screw to adjust the gap between the contacts so there is a very small space between them, and when turned on, there is a continuous oscillation and a spark jumping between the contacts. *Turn the power off before readjusting the screw.*
- Check to see that the fuse is unbroken.

S **Setting up the Induction Coil**

- Make sure that the induction coil is connected only to 6V DC current (middle setting on the power pack).
- Connect the positive terminal of the induction coil to the positive terminal of the DC power supply and the negative terminals similarly.
- Pull the terminals on the secondary coil apart before connecting to a discharge tube.

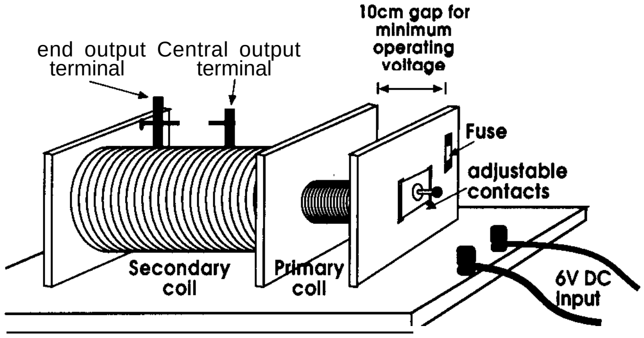
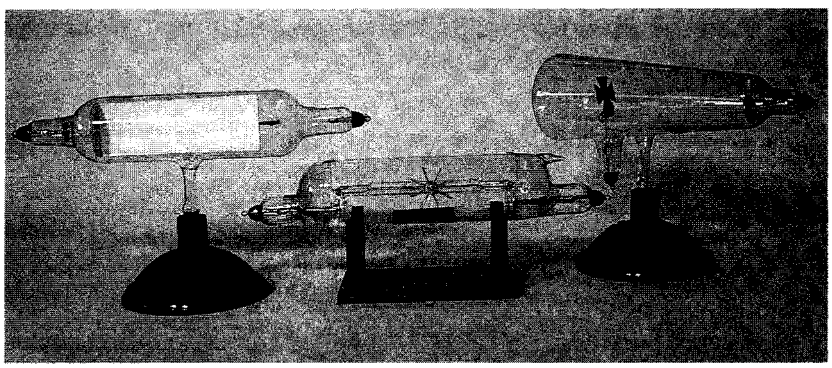


figure 1

- To achieve a *minimum operating voltage,* move the position of the secondary coil so there is a gap of 10cm between the front section of the primary and secondary coils *as shown in the diagram.*

2) CROOKE'S TUBES

Crooke's tubes are a set of 3 discharge tubes which, when connected to a high voltage power supply such as the induction coil, demonstrate the existence and some of the properties of 'cathode rays'.



They are all clear glass evacuated tubes with a plate cathode (–) and nipple-shaped anode (+). The magnetic deflection tube has a vertical fluorescent screen in the tube to highlight the path of the cathode rays. The Maltese cross tube has a metal cross in the tube which can be flipped up into the path of the cathode rays. The paddlewheel tube sits horizontally in a wooden cradle with a glass paddlewheel positioned to turn in the path of the cathode rays.

SETTING UP AND USING CROOKE'S TUBES

C **It is worth checking the following before setting up the equipment.**

- Use a large horseshoe magnet or electromagnet for deflecting the beam.
- Position the discharge tube to point towards the wall so that the student is one metre away and any X-rays produced when the cathode rays hit the glass will be absorbed by the wall.

S **Setting up Crooke's Tubes**

- Connect up the induction coil to the power pack *as described in the section on the induction coil.*
- For the magnetic deflection and Maltese cross tubes connect the central output terminal on the induction coil (*see figure 1*) to the cathode plate electrode in the tube, and the end terminal of the induction coil to the nipple-shaped anode in the tube. If a green fluorescence is not clearly visible at the 'cross' end of the tube opposite the cathode then change the polarity of the connections.
- Position the paddlewheel tube exactly horizontally on the wooden cradle. The paddlewheel should be resting at one end of the tube. Connect this end, as the cathode, to the central terminal of the induction coil. Connect the end terminal to the anode.

SUGGESTED LEARNING EXPERIENCES

TOPIC: Atomic Physics - History of the Atom

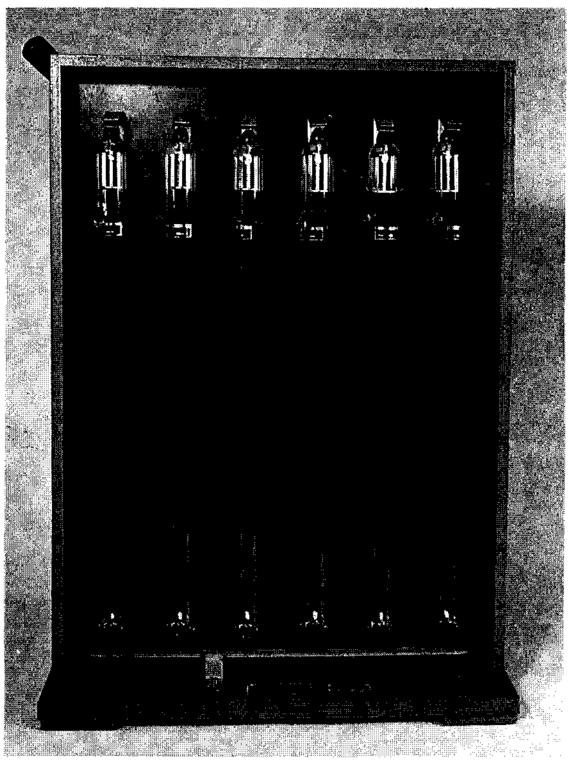
1. **Use the *Maltese cross tube* to demonstrate the following characteristics of cathode rays:**
   - that they are emitted at right angles to the cathode
   - that they travel in straight lines in a vacuum (since they form a shadow of the cross on the glass)
   - that they are interrupted by a thin piece of metal.

   Set up the experiment as described earlier with the cross down to view the fluorescence on the end of the tube, switch it off, flip the cross up into the path of the cathode rays and switch it back on. HINT - with a black piece of material, provide a dark background at the end of the tube to see the fluorescence more easily.

2. **Demonstrate that cathode rays are deflected by a magnetic field and therefore carry charge,** by using the ***magnetic deflection tube.*** Set up the equipment as described earlier and place a large horseshoe magnet over the tube so the magnetic field is at right angles to the path of the cathode rays. Reverse the polarity of the magnet and discuss the results.

3. **Demonstrate that cathode rays have momentum and therefore mass,** by using the ***paddlewheel tube.*** Set up the equipment as described above and switch it on. The paddles on the wheel are painted with fluorescent paint to show when the cathode rays are hitting them. The paddlewheel is propelled along by the impact of collisions with the cathode rays, revealing that they must have mass.

3) TUBES FOR VACUUM SCALE



These tubes are used to demonstrate the concept of mean free path of electrons and to display the results of early physicists in their quest to discover the nature of cathode rays.

This equipment consists of a set of six glass tubes evacuated to decreasing levels of gas pressure. Only one tube is connected at a time to a high voltage power source such as the induction coil.

Varying patterns of fluorescence and dark spaces are observed as the pressure in the tubes decreases.

SPECIFIC SAFETY PRECAUTIONS

- Always hold the moveable connection at the back of the equipment by its plastic insulating handle.
- Switch the apparatus off while changing the moveable connecting arm.
- ***Keep one hand behind your back when touching the equipment while it is turned on.***

SETTING UP AND USING THE TUBES FOR VACUUM SCALE

Setting Up the Equipment

- Connect the induction coil to the power pack ***as described in the section on the induction coil.***
- Connect the central output terminal of the induction coil (see figure 1) to the moveable handle at the back of the discharge tubes (connects to the cathodes) and the end output terminal of the induction coil to the bottom connection at the front of the discharge tubes (connects to the anodes).

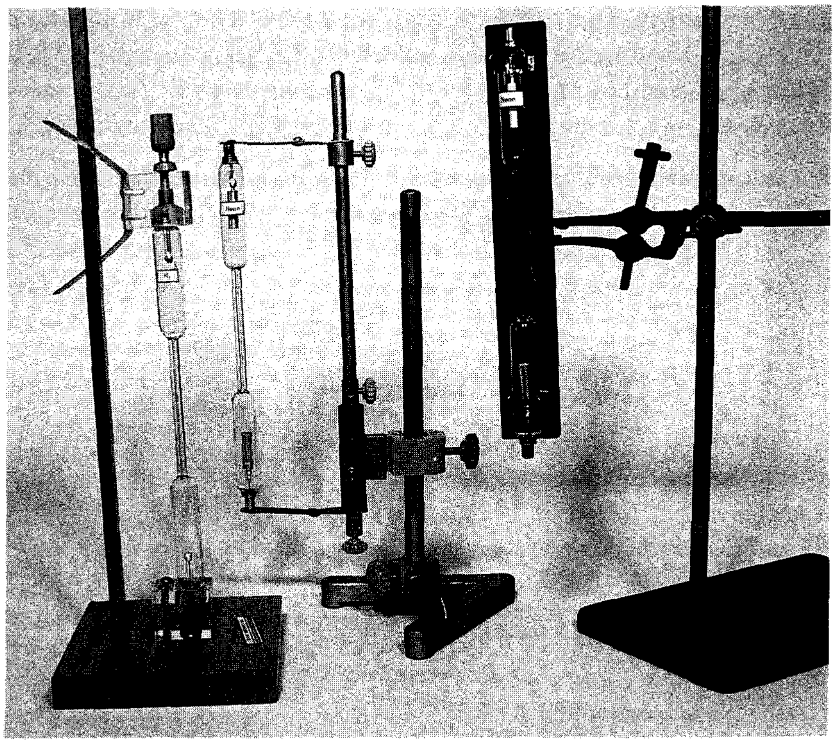
SUGGESTED LEARNING EXPERIENCES

TOPIC: Atomic Structure

1. Observe the nature of cathode rays as Crookes would have seen them and discuss your observations in the light of your knowledge of electrons today. ***Refer to Activity 17.1 page 94 Essential Physics.***
2. Discuss how the concept of the mean free path of electrons explains the dark spaces appearing in some of the columns.
3. Use the lower pressure tubes to demonstrate the effect of an aurora and discuss the concept of ionisation.

4) SPECTRUM TUBES

This equipment consists of a number of glass discharge tubes which can be mounted individ-ually in a stand.



The tubes contain different gases, including hydrogen, neon, helium, and sodium vapour. When connected to a high voltage power source they emit a fluorescence which is peculiar for the particular element contained in the tube. They are ideal light sources to use with the hand spectroscope or spectrometer (see ***pages* 43 *and 46).***

SETTING UP AND USING THE SPECTRUM TUBES

C **It is worth checking the following before setting up the equipment.**

The hydrogen gas discharge tubes have a lifetime of the order of five years, after which a significant proportion of the gas has diffused through the glass container. Each tube should be tested annually and more tubes ordered as required.

S **Setting up the Spectrum Tubes**

- Connect the induction coil to the power pack *as **described in the section on the induction coil, page 28.***
- Connect the output terminals of the induction coil to the terminals of the discharge tube - the polarity does not seem to matter.

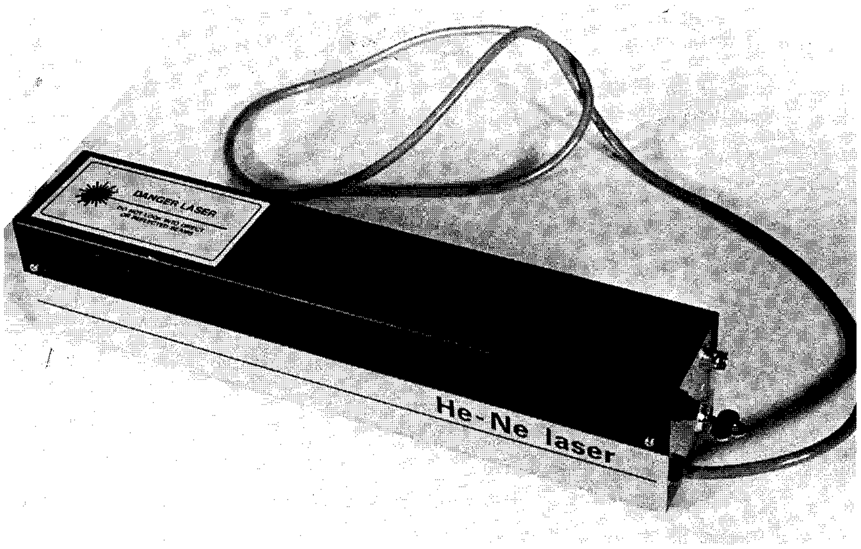
SUGGESTED LEARNING EXPERIENCES

TOPIC: Atomic Physics

1. **Observe the spectral lines of hydrogen** using a diffraction grating spectrometer and the hydrogen gas spectrum tube. Take measurements of the angular positions of the lines and calculate the wavelength and frequency of each visible line. ***Refer to activity 17.2 page* 96 *Essential Physics.***
2. **Using a collection of different discharge tubes with their labels covered, ask students to identify the gases within them** by observing their emission spectra and comparing these with known charts.

LASER

The laser is a light source which produces a concentrated beam consisting of photons travelling in the same direction, in phase with each other and having the same wavelength-a completely coherent beam of light. This can be used as a powerful and effective source for many experiments demonstrating the properties of light.



The LASER (acronym for Light Amplification by Stimulated Emission of Radiation) comes fully contained within a metal housing, the beam emerging from a small hole in the centre of the front of the box.

SAFETY PRECAUTIONS

- A *laser safety sign* must be displayed at all entrances to the lab when the laser is being used.
- To comply with Department regulations, the power output should be less than 5 mW. At this energy level, the laser is considered safe for use in schools.
- Do not operate the laser at eye-level as the beam, if deflected into the eye, could do serious damage to the retina.
- Do NOT darken the room more than is absolutely necessary as this enlarges the pupil of the eye thus increasing the risk of eye damage.
- Before switching on the laser consider what surfaces around it might reflect the beam (glassware, metal fixtures, etc). *Remove or cover all reflective surfaces.*
- The laser must not be moved when switched on.
- When not in use either turn it off or block the beam at the laser.

SETTING UP AND USING THE LASER

C **It is worth checking the following items before an experiment is set up:**

- Make sure you have the key to activate the laser.
- Remove or cover all reflective surfaces (glassware, metal fixtures, etc).

Extra equipment for the suggested learning experiences (numbers refer to appropriate experiences) includes:

- a retort stand, bosshead and wooden peg
- a white screen
- graph paper
- sticky tape

- plasticine
- a meter rule
- a diffraction grating (3)
- celluloid slides with single and double slits etched into them (1, 2)
- a compact disc (4)
- a microscope slide with a small dot of liquid paper on it (6)
- a sewing pin (small steel head) (7)
- colloidal suspension (milk powder in water) (5)
- pieces of polaroid (5)
- large (3L) glass beaker (5)
- converging lens (focal length 10cm) (6)
- diverging lens (focal length 5cm) (6)
- 'gem' single-edged razor blades (2)

Setting up the laser

- Place the laser on a bench or other stable fixture that is not at eye-level.
- Set up the screen between 1 and 2 metres away from the laser
- The laser beam exits through the middle hole at the end opposite the switch. Align the screen with this hole and check for reflective objects in its path.
- Switch on the laser by turning the key at the back.
- The laser will take 15 minutes to reach full power.
- Set the object to be studied between 2 and 10 cm away from the front of the laser. This may be held in a clamp attached to a retort stand or it may be attached to the desk using plasticine.

HANDY HINTS

The width of the laser beam, quoted in the specifications, is probably less than 1 mm. Some experiments may require the laser beam to be spread into a wider parallel beam (eg Poisson's spot and some double slit experiments). This can be achieved by placing a diverging lens (f = 5cm) and a converging lens (f = 10cm) spaced 1 Ocm apart in wooden lens holders between the laser and the object.

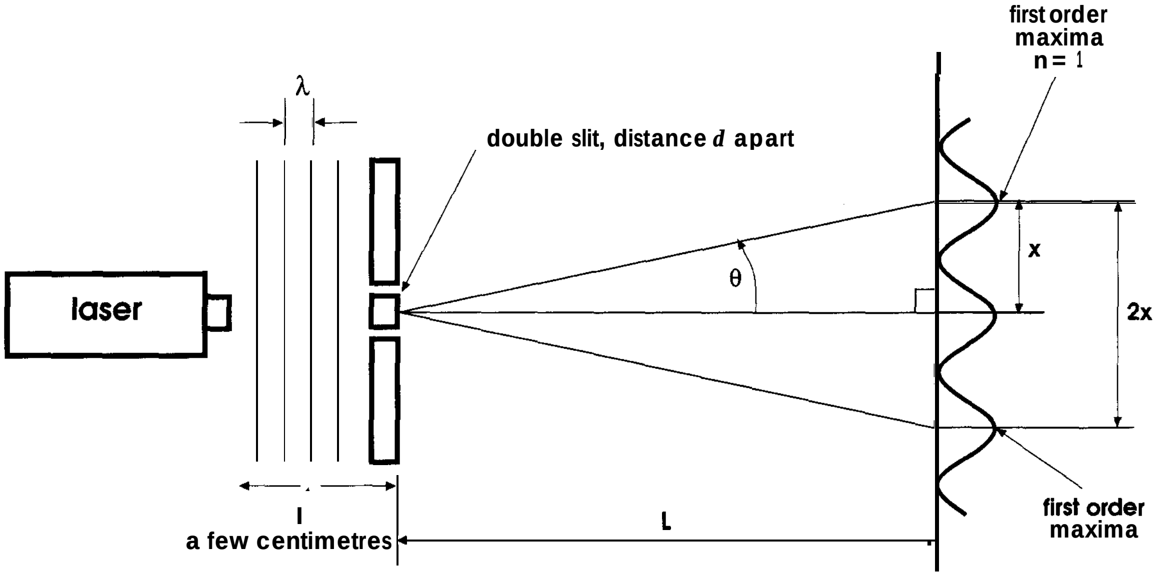


figure 1

SUGGESTED LEARNING EXPERIENCES

1. **Demonstrate Young's double slit experiment and measure the wavelength of the laser beam.**

Set up the prepared celluloid slide with various widths of double slit in the path of the laser beam. Aim the beam at the narrowest microscopic slits in the black strip found at the top of the slide. Observe the interference pattern produced on a screen about 1 metre away.

Measure the slit separation (d), distance to the screen (L) and the distance from the central maximum to the first order maximum (x).

To find the wavelength (λ) of light emitted by the laser, use the following equation :

$$\sin \theta = \lambda / d$$

where θ can be found from the equation $\tan \theta = x/L$. *See figure 1.*

Discover how the interference pattern changes as both the slit separation and the distance to the screen are independently varied. ***For more details see Activity 18.7 in Essential Physics.***

2. **Observe the Fraunhofer diffraction pattern from a single slit.**

Set up a variable width single slit using two 'gem' single-sided razor blades held in the path of the laser beam. Use plasticine to hold the blades in place. Observe the diffraction pattern on a screen 1 metre away from the slit. Observe and record how this pattern changes when both the slit width and distance to the screen are independently changed. ***For further details see Experiment C-7in Year 12 Senior Physics.***

3. **Calculate the wavelength of the laser beam using the diffraction pattern from a diffraction grating.** Set up a prepared slide containing a diffraction grating in the path of the laser beam. Observe the pattern on a screen 1 metre away. Use the formula $d \sin \theta = m \lambda$, where $m = 1$ for the distance from the central bright fringe to the first lateral maximum. ***For further details see Experiment C-8 in Year 12 Senior Physics.***

4. **Observe the diffraction pattern from a compact disc or vinyl record (reflection).**

Observe the diffraction pattern obtained by reflecting the laser beam off the face of a compact disc. Vary the angle of reflection and observe the results. Be very careful that the reflected light is not at eye-level.

5. **Observe polarisation by scattering**

Mix a colloidal solution of milk powder in water in a large 3L beaker. Direct the laser beam down through the middle of the beaker and observe the polarising effect by viewing the scattered light through pieces of polaroid at different angles. Be careful not to look directly into the laser beam.

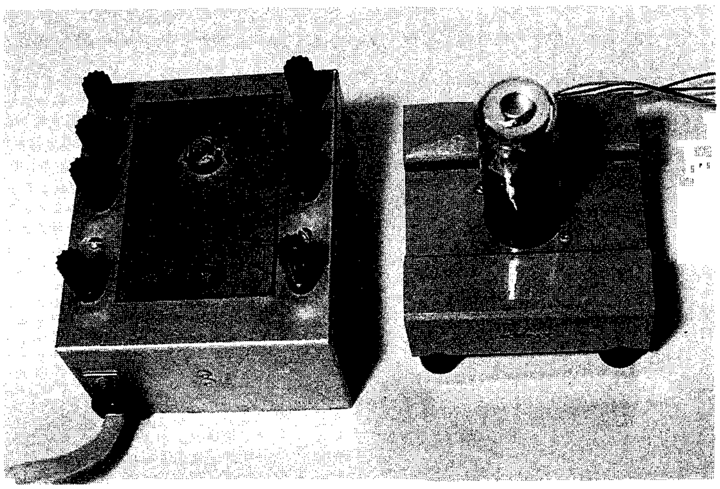
6. **Observe Poisson's spot**

Place a small dot of liquid paper on a microscope slide and position it in the path of the laser beam. The 'dot' must be smaller in diameter than the laser beam (see ***Handy Hint section).*** Observe the diffraction pattern around the edge of the spot as it is projected on to screen about 1 m away. Observe the shadow of the dot and the central bright spot caused by constructive interference of the diffracted rays around the edge of the 'dot'.

7. **Observe the diffraction pattern around a small object such as the head of a pin.**

Broaden the beam from the laser using the method outlined in the Handy Hint section. Place the head of a pin in the path of the laser beam and observe the diffraction fringes around the edge of the shadow projected onto a screen a short distance away.

MASS OF THE ELECTRON KIT



This kit is used to calculate the charge-to-mass **(q/m)** ratio of an electron and ultimately the mass of the electron itself. It consists of a special *valve* mounted in a socket, fitted to a base. The valve is a vacuum tube with a central cathode surrounded by a bowl-shaped anode. The anode is coated with a fluorescent material which emits flashes of light when electrons impinge on it.

The electron path is observed to curve when the valve is placed in the uniform magnetic field from a solenoid. (*See figure* 2).

The radius (R) of this curve is measured and used, with the magnetic field strength **(B)** and the accelerating voltage **(V)** of the electrons, to calculate the mass-to-charge ratio **(q/m).**

SAFETY PRECAUTIONS

- When using the high voltage power supply be careful to secure the connections safely.
- Do not touch the connections when the power is turned on - *work always with one hand behind your buck* to avoid getting an electric shock.
- Do not touch the glass tube when the power is on, as low energy X-rays may be produced when the electrons are stopped suddenly in the glass.

SETTING UP AND USING THE MASS OF THE ELECTRON KIT

C **It is worth checking the following items before an experiment is set up**

- Ensure that you have an appropriate high voltage power supply (0-200V). An especially designed power source was originally available with the kit (see *above photograph).* If this is no longer available, the power source supplied with some cloud chambers will also work effectively.
- Calculate the magnetic field strength **(B)** at the centre of the solenoid for a given current **(I). This** value can be determined from a calibration graph for the solenoid of **B** against **I** drawn up using the current balance kit. *(See page 21).*

  An alternative method for determining the value of **B** is to use the formula

$$B = \frac{4 \times 10^{-7}\, NI}{\sqrt{l^2 + d^2}}$$

where **I =** the current in the solenoid,
d = the average diameter of the solenoid.
N = number of turns in the solenoid
l = length of the solenoid

X **Extra equipment for the suggested learning experience includes:**

- an air-core solenoid from the current balance kit
- 2 power packs
- 1 rheostat or variable resistor
- cork borers of varying sizes to use as templates
- a special high voltage power supply (0-200V)
- an ammeter
- 4 leads
- vernier callipers

Setting up the Mass of Electron Kit

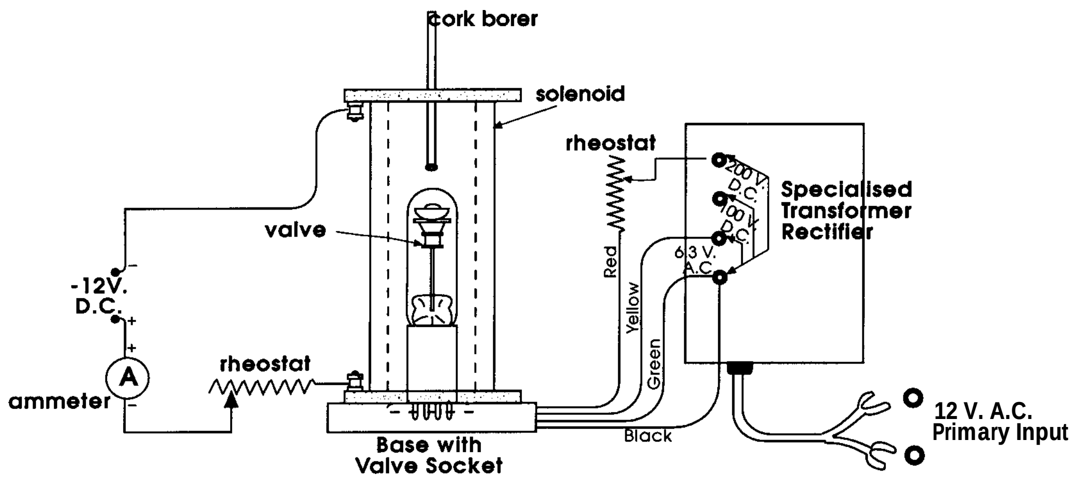


figure 1

- Set up the equipment in two separate circuits, as shown in figure 1.

  One circuit, which consists of the rheostat, ammeter andpowerpack, is used to supply a uniform magnetic field in the centre of the solenoid.

  The other circuit consists of the valve and its power supply, set up in the following way:
  - Connect the green and yellow wires from the valve across the 6.3 volt terminals of the power supply. These are used to heat the filament of the cathode.
  - Connect the red and black leads across the 200 volt terminals of the power supply -the red is connected to the anode and goes to the positive terminal, while the black is connected to the earth or negative terminal. This supplies the accelerating voltage (V) to the electrons.
- Place the solenoid in a vertical position over the top of the valve.

HANDY HINTS

- After the valve is turned on several minutes are required for the filament to heat up.
- Use the vernier callipers to measure the inside and outside diameters of the solenoid and then calculate its average diameter (d). See *Yr 12 Senior Physics Lab Manual p61.*

SUGGESTED LEARNING EXPERIENCE

Calculate the mass of an electron using the following expression

$$m = \frac{B^2 q R^2}{2 v}$$

where **R =** the radius of curvature of the electron path (see *method below),*

B = the magnetic field strength at the centre of the solenoid

V = the accelerating voltage

q = 1.6×10^{-19}C (the known value for the charge on an electron)

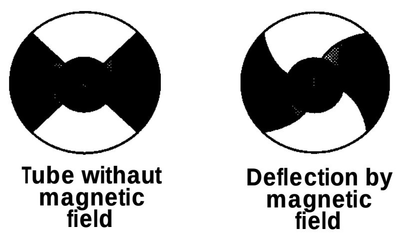


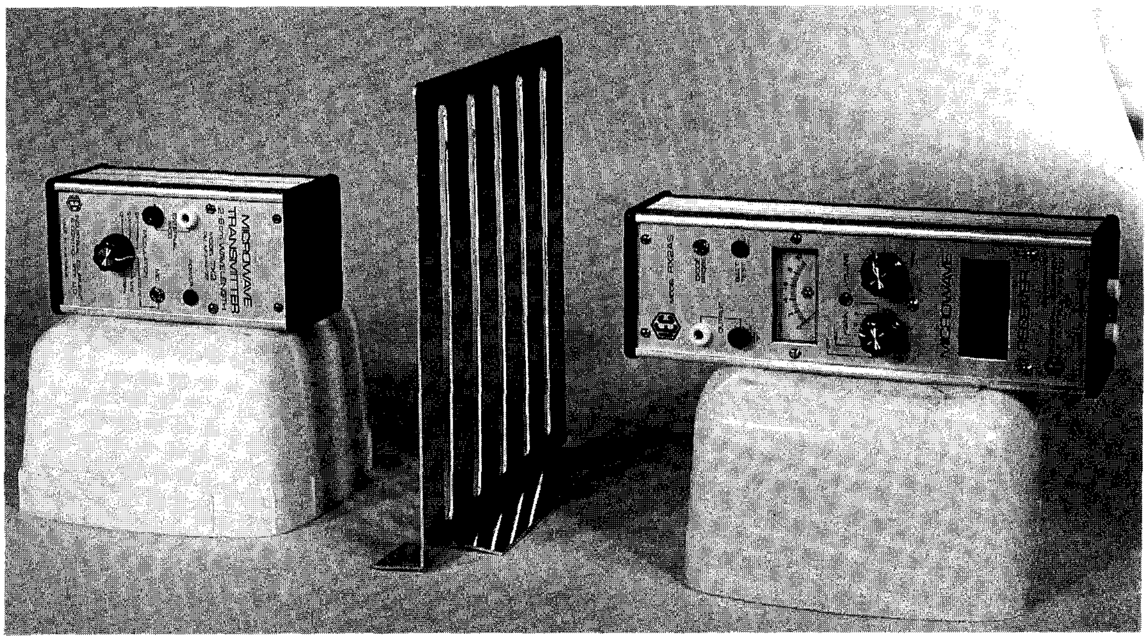
figure **2**

This expression has been derived from equating the two equations for the magnetic force on the electrons **F = BqV** and **F = mV²/R.**

An easy method for measuring R

In order to measure the radius of curvature (R) use a cork borer as a template. Select a large cork borer and, looking through the borer to the top of the valve, adjust the current flowing through the wire loop so that the electron path exactly fits the curvature of the selected cork borer. Measure the diameter of the cork borer with the vernier callipers and calculate the radius of curvature of the electron path. Figure 2 shows the top view of the valve when the magnetic field is turned off and when it is turned on. See ***the PSSC Lab Manual page 79 for further details.***

MICROWAVE KIT



The microwave kit is an excellent tool to demonstrate the similarities in the properties of microwaves and lightrays. This canbeextrapolated to suggest the similarities the properties of all electromagnetic radiation.

A major advantage in working with microwaves is that the long wavelength allows experimental measurements to be taken with protractors and metre rules.

The beam of microwaves is also perfectly polarised and monochromatic which allows it to be used as a 'long wavelength laser' to demonstrate properties of electromagnetic waves such as reflection, refraction, absorption, diffraction, interference, polarisation, the inverse square law, doppler effect and radio transmission.

The microwave kit consists of a microwave transmitter, a receiver and a number of accessories including a diode probe unit, hollow shapes, wax lenses, metal screens and grids.

The transmitter produces microwaves of approximately 3cm wavelength and 9000 MHz frequency at a power output of 10 mW. The microwaves are produced inside a rectangular waveguide fitted with a horn from which they emerge, plane polarised vertically (electric component) and completely coherent. The microwaves are modulated by an audio oscillator to enable the user to hear where the intensity of radiation is a maximum or minimum.

The receiver consists of a dipole in a tuned waveguide section fitted with a horn. This enables it to discriminate the direction of polarisation of the electric field. A second receiver, called a diode probe unit, is not as sensitive as the horn receiver, but detects microwaves through a 360° arc.

SAFETY PRECAUTIONS

The microwave equipment is safe to use because the poweroutput is so low. *- 10^{-5} times thepoweroutput of an average microwave oven.* However, since excessive microwave energy can destroy tissue, a few recommended safety measures have been set out as follows:

- Don't look directly into the beam at close range (1 m).
- Take particular care when using the wax "lenses", as they focus the intensity of the beam to a point.
- Avoid reflective surfaces, such as metal taps, which might reflect the beam in many different directions.
- *Do NOT connect the older style receivers to a power supply, as this will destroy it.* (A power supply is only required to run the audio amplifier.)

SETTING UP AND USING THE MICROWAVE KIT

It is worth checking the following before setting up the equipment.

- There are many different models of this equipment, varying mostly in the design of the receiver. In some models a milliammeter and audio amplifier are included internally while in others, just the milliammeter. It is important to follow the instructions appropriate for your model.
- Check the fuse in the transmitter - in the newer models, it is located internally.

X Extra equipment for the suggested learning experiences includes:

- a meter rule
- 2 power packs
- a demonstration microammeter *(if not included in the receiver)*
- an audio amplifier *(if not included in the receiver)*
- *8* leads with banana plugs
- a protractor
- large sheets of paper
- paraffin oil

Setting up the Microwave Equipment

- Connect the microwave transmitter to the AC terminals of a power pack or klystron power supply, if applicable. Switch the power supply to 12 V AC ('G' setting).
- Connect the audio amplifier, *if not included in the receiver,* to the AC terminals of the other power pack. Switch the power supply to 12 V AC ('G' setting).
- Connect the milliammeter, *if not included in the receiver,* to the microwave receiver and to the input terminals of the audio amplifier. *See figure 1.*
- Position the transmitter and receiver facing each other and approximately 1 metre apart.
- Elevate both the transmitter and receiver above the desktop to avoid unwanted reflections from the wood. (Especially the smaller, newer models.)
- Switch on the transmitter and set it to 1000 Hz. Where possible, 'tune' the transmitter to produce a maximum reading on the milliammeter.
- Switch on the receiver and, where appropriate, choose a *'gain'* setting and volume setting which gives close to a full scale deflection on the internal meter.
- Turn the transmitter off and record the background reading on the milliammeter. Use this as

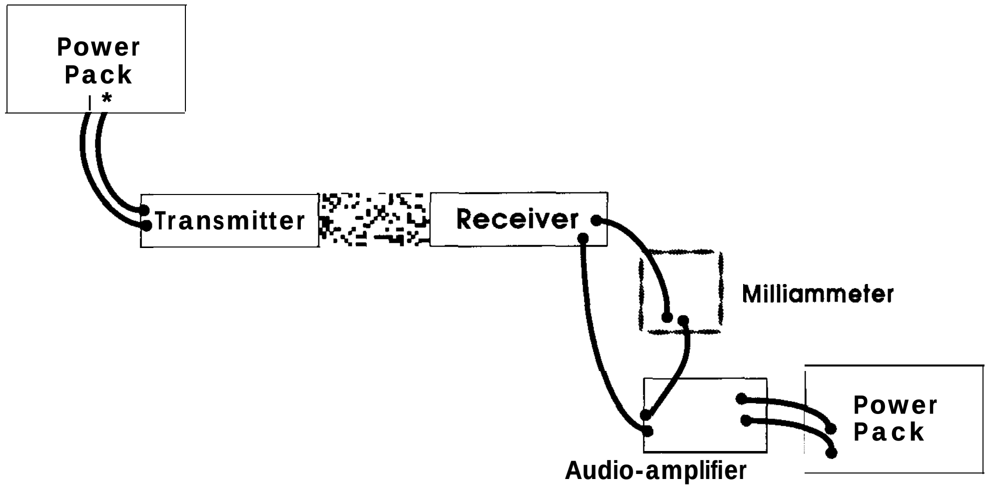


figure 1

your 'zero' reading for all future calculations. If you change the gain setting on the receiver of the newer models you will have to note the new "zero' reading for each setting used.

- When using the diode probe unit, connect it to the receiver and check that there are no reflective surfaces nearby to affect the results.
- To avoid spurious results, use reflective screens between the transmitter and detector when they are side by side.

HANDY HINTS

- Use a metre rule to align the transmitter and receiver with each other.
- When using the newer IEC model, *do notforget to switch off the receiver after use* as it contains an internal battery which, if left on, will quickly become flat.
- You will need a large working space to set up most of the following learning experiences -one large bench or perhaps spread over two benches.

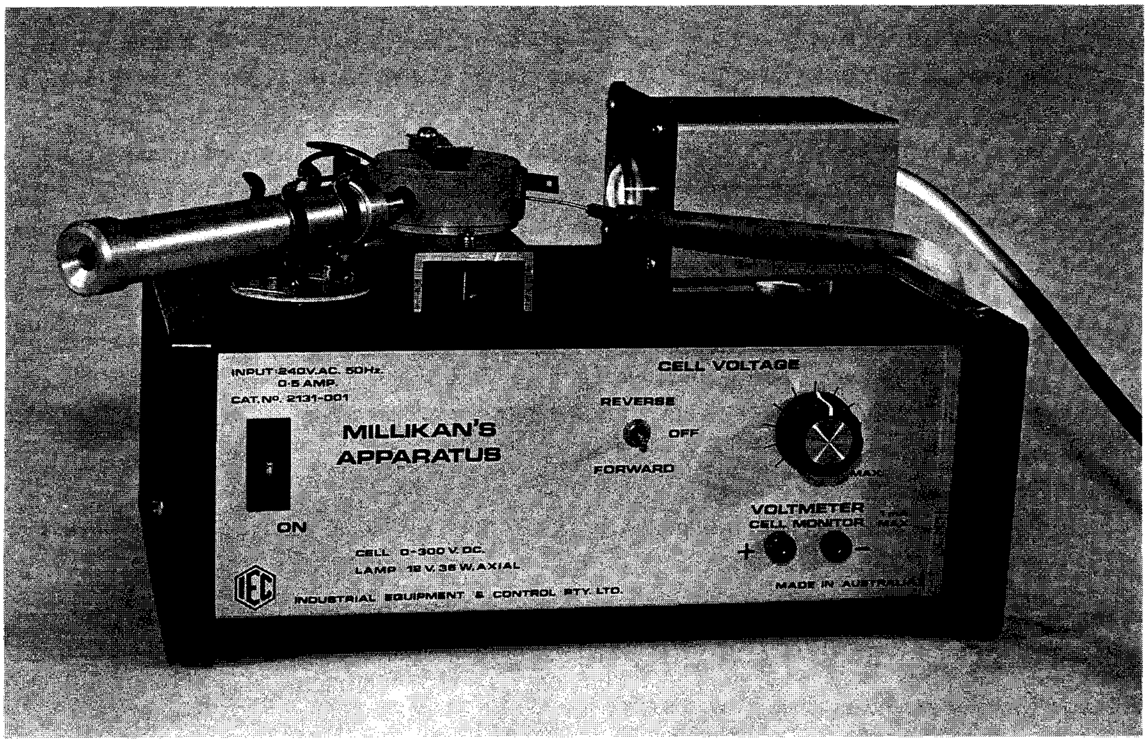
SUGGESTED LEARNING EXPERIENCES

TOPIC -Electromagnetic Radiation

The microwave equipment is a versatile tool for demonstrating many important principles. The manual which accompanies the kit contains detailed instructions for the procedure of each of the following demonstrations:

1. **The similarities in the behaviour of microwaves and light rays** can be shown by performing similar experiments with a ray box as with the microwave kit.
2. **The law of reflection,** using the metal screen and other curved surfaces.
3. **Absorption and partial transmission,** using a sheet of perspex or masonite.
4. **Polarisation of microwaves** using the metal polariser provided.
5. **The law of refraction** through the wax objects and the hollow prism filled with liquids such as water and cooking oil. NOTE: water absorbs the microwaves, showing the principle of microwave cooking.
6. **The refractive index of wax** can be calculated, using wax prism.
7. **The phenomenon of total internal reflection** using wax prism.
8. **The phenomenon of standing waves** using two reflecting surfaces.
9. **The diffraction of waves** around the straight and curved edges of objects.
10. **Diffraction through a single slit** using the metal sheets.
11. **Interference through a double slit** using metal sheets of different sizes.
12. Diffraction through a diffraction grating, using the metal grate provided.
13. Thin film interference using sheets of perspex and metal.
14. The inverse square law for electromagnetic radiation.
15. The doppler effect using a moving source.
16. Demonstrate the concept of radio transmission using a microphone to modulate the wave.

MILLIKAN'S OIL DROP



This equipment has been designed to enable students to calculate the charge on an electron in a similar way to that devised by Millikan in 1912.

It consists of a transformer which supplies a high voltage to two metal plates located inside the chamber which is mounted on top. A small telescope is fixed to focus into the middle of the chamber and an atomiser mounted so that an attached needle can be inserted into the side of the chamber.

Using this equipment the value of the charge on the electron can be determined by balancing the gravitational and electric forces on small charges particles of latex which have been injected from the atomiser into the cavity.

SETTING UP AND USING MILLIKAN'S OIL DROP

C **It is worth checking the following items before setting up an experiment**

- Ensure that the needle used to inject the latex mist is not blocked with hardened latex. It can easily be cleared with a piece of thin wire.
- Ensure that the tubing and neck of the atomiser is cleared of hardened latex.
- Check that the consistency of the latex solution is a fine fluid suspension. If it is too thick, dilute with water. If the fine particles of latex are clumped together they cannot be used.
  NOTE: The latex is supplied in a concentrated form and needs to be diluted 1 in 10 parts with water (5 ml of latex solution made up to 50 ml with water).
- Always wash the equipment thoroughly before putting it away.

X **Extra equipment for the suggested learning experience includes:-**

- a DC voltmeter (0-300 volts) OR a multimeter
- connecting leads
- a piece of black material as a hood for the apparatus.
- a strip of black plastic
- thin wire to focus the telescope

Setting up Millikan's Oil Drop

- Darken the room or place a piece of black material over the apparatus and the person viewing the particles. The voltages can be read by a second person outside the hood.
- Turn on the lamp and position it to illuminate the inside of the chamber. For some models without an inbuilt power supply you will need to connect a 12 volt power supply to operate the lamp.
- Ensure that the transformer switch is in the middle position so that the plates inside the chamber are not charged.
- Insert a small piece of thin wire into the middle of the chamber through the injection hole.
- Focus the telescope by sliding it in and out, so that the edges of the wire can be clearly seen. NOTE: the image in the viewer is inverted and will appear on the side opposite the insertion point.
- Place a strip of black plastic at the back of the chamber to act as a screen.
- Remove the wire and insert the needle.
- Squeeze the atomiser a couple of times. The latex particles should be seen as tiny pin points of light drifting slowly upwards, because the image is inverted.
- If the latex particles cannot be seen adjust the light source by sliding it in its mount towards the chamber.
- Re-focus the telescope viewer.
- Connect the voltmeter or multimeter to the transformer, so that the voltage across the plates can be read.

SUGGESTED LEARNING EXPERIENCE

This equipment is used exclusively to determine the charge on an electron.
These results may then be used, in conjunction with Thomson's charge/mass ratio equipment, to determine the mass of the electron.

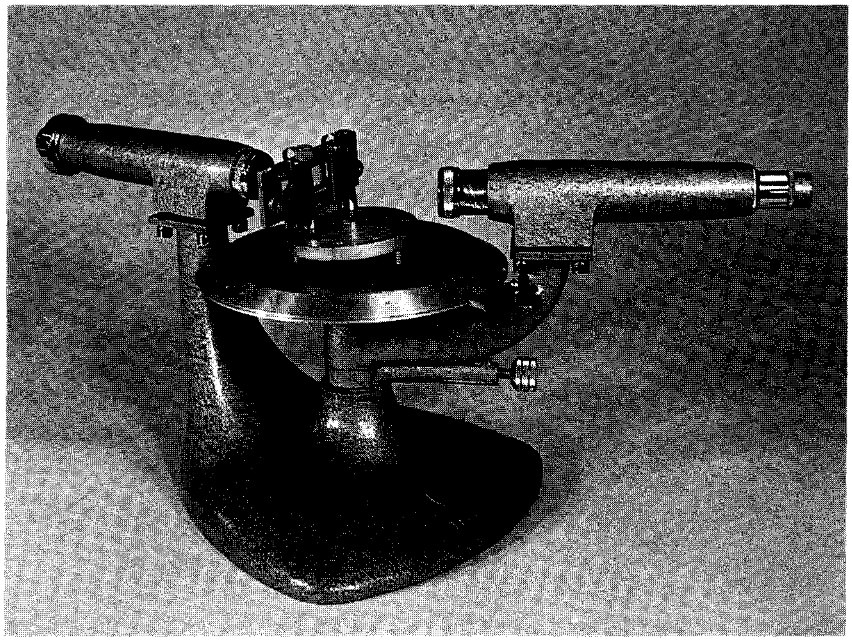
Procedure

- Set up the equipment as described, with the telescope focused on the latex particles which are seen to drift upwards. Set the voltage to about 200 volts by rotating the 'cell voltage' control knob in a clockwise direction.
- Reverse the polarity of the plates a couple of times using the switch on the front of the transformer. This will cause the fast moving particles to move from the field of view.
- Concentrating on one of the slowly moving particles, adjust the voltage until the particle stops moving.
- Record the voltage. This is the voltage required to balance the particle against the force of gravity exerted on it.
- Obtain readings of the balancing voltage for a large number of particles (approximately 50).
  NOTE: Any particle which is balanced with a voltage less than 50 volts should be ignored, as its own charge is caused by too large a surplus or deficit of electrons. This means that the chance of getting readings which differ from each other by the equivalent of 1 electron is very small. Some readings in excess of 200 volts should be obtained.
- This number of readings may take several periods to collect.

Analysis

- The results should seem to clump together in groups. Calculate an average value for each of the 3 or 4 groups with the highest voltages.
- Convert these values to $1/V$ and list them in order. The charge on the particles is proportional to these $1/V$ values.
- The actual values of the charges are calculated by multiplying the $1/V$ values by the mass of the spheres, the acceleration due to gravity and the distance between the charged plates,
  where $e^- = mgd/V$
- The mass of the particles is calculated from the average volume and density of the latex. The manufacturer has specified the average diameter of the latex particles to be 1 micron and the density of the latex as between 0.94 and 0.98 gcm^{-3}. The charged plates are 5 mm apart.

SPECTROMETER



The bench spectrometer is an instrument used for measuring the wavelengths of light.

The most important application of the bench spectrometer is to determine the individual wavelengths present in atomic emission spectra.

The spectrometer comprises three parts; thecentralcirculartable, the collimator and the telescope. A prism or diffraction grating is mounted in the centre of the table which is graduated in degrees. With the aid of the vernier scale, angular measurements to 0.1° are easily made.

The collimator is a fixed arm with an adjustable slit at one end and a lens at the other for focusing the image of the slit.

The telescope is a moveable arm with an achromatic lens at one end and an eye-piece with cross-hairs at the other.

SETTING UP AND USING THE SPECTROMETER

It is worth checking the following items before an experiment is set up

- Ensure you have the box of accessories which includes:
  - a screw-threaded post with a spring clip for holding the flint glass prism firmly on the circular table
  - an L-shaped bracket with 2 spring clips for holding the diffraction grating.
  - an optically worked 60° flint glass prism. (This is a very expensive prism and not to be confused with the crown glass prisms used in the junior school.)
  - a replica diffraction grating mounted in black cardboard with 3 small glass windows labelled in lines/inch.

Extra equipment for the suggested learning experiences (numbers refer to appropriate experiences) includes:

- 2 metres of thick black cloth for covering the instrument and your head.
- a tungsten light bulb and desk lamp mounting (1)
- a sodium vapour lamp with mounting and power supply (2,3,4,5)
- a mercury vapour lamp with mounting and power supply (6)
- a 'long-life' light bulb and appropriate mounting (6)
- a kit of spectral tubes including hydrogen, helium and neon, induction coil, power pack and leads (6,7) - See ***instructions for setting up spectral tubes on page*** 30.

Setting up the Spectrometer

- Look through the eye-piece and adjust until the cross-hairs are sharp and clear.
- Point the telescope at some distant object like a building or a tree and adjust the achromatic lens until the inverted image is in sharp focus. The telescope is now focused at infinity and should not be adjusted again throughout the experiment.
- Place any bright light source at the slit end of the collimator and swing the telescope into line so that a bright vertical image of the slit can be seen.
- Adjust the achromatic lens at the end of the collimator until the image of the slit comes into sharp focus. It is this step which is repeated during the course of any experiment. That is, the slit-width adjusted and the collimator lens re-focused to give a sharp image of the slit.
- Depending on the experiment, mount either the prism or the diffraction grating on the central circular table and place the appropriate light source at the adjustable slit.
  Remember: apart from adjusting the slit-width, the ONLY focusing adjustment made during the course of an experiment is re-focusing the lens at the end of the collimator. The telescope always remains focused at infinity.

HANDY HINT

- Set the spectrometer up in a darkened laboratory or cover the instrument and your head with a piece of thick black cloth.

SUGGESTED LEARNING EXPERIENCES

1. **View a continuous spectrum from red to violet** using a 12 volt tungsten filament bulb as the light source and a 60° prism on the table. Moving the telescope aside, try looking directly through the prism to obtain the best orientation for seeing the spectrum (*see figure* 2).
2. **View the sodium emission spectrum** using the sodium vapour lamp and **60°** prism.
3. **Calculate the refractive index of the prism** using the sodium vapour light and th**60°** flint glass prism. First determine the refracting angle of the prism (*see figure 1*) by positioning the prism so that the incident light falls on one of the vertices. Position the telescope to receive the *reflected* light from each of the faces either side of the edge of the prism. Read off the angular displacement from the vernier scale on the turntable and the angle between the two readings is twice the refracting angle (A) of the prism.

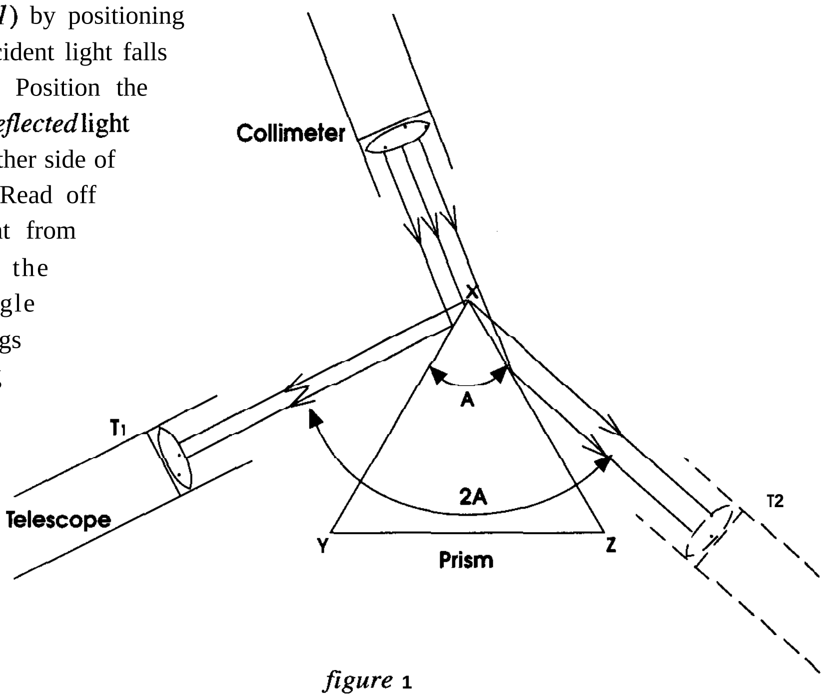


figure 1

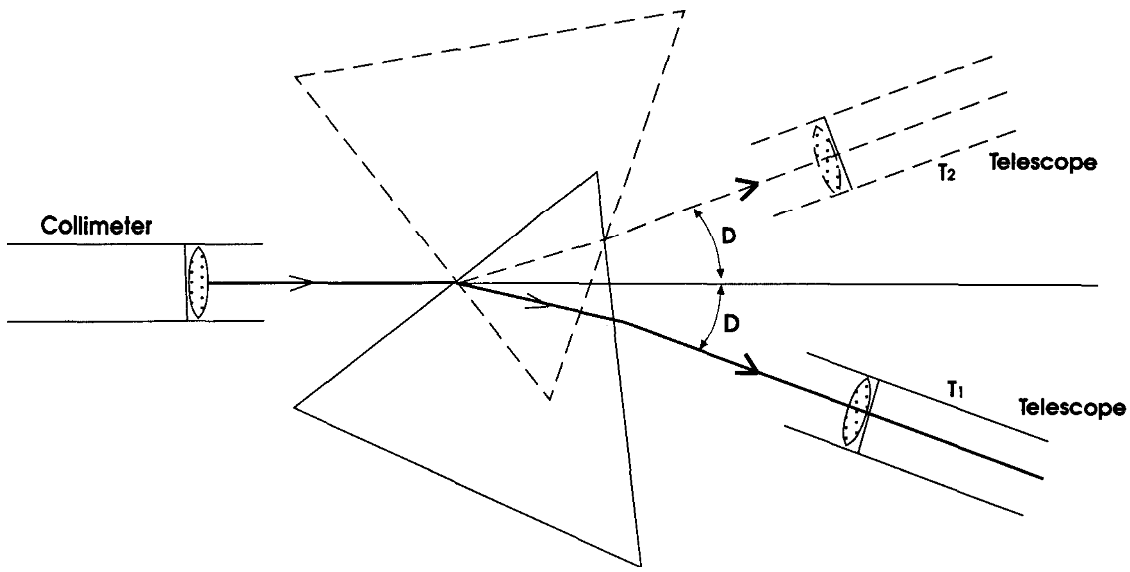


figure **2**

The angle of minimum deviation can be found by positioning the prism (*see figure* 2) so that the light is incident at about $45°$ to one of the refracting faces and the telescope set up to receive the *refracted* light through the prism. Rotate the prism table slowly, reducing the angle of incidence till the refracted beam is on the point of reversal. Read off the angle from the vernier scale. Rotate the prism to bring the other refracting face toward the collimator and repeat the procedure. The angle between the two readings taken is twice the angle of minimum deviation (D). Calculate the refractive index of the prism using the following formula

$$n = \frac{\sin (A+D)/2}{\sin A/2}$$

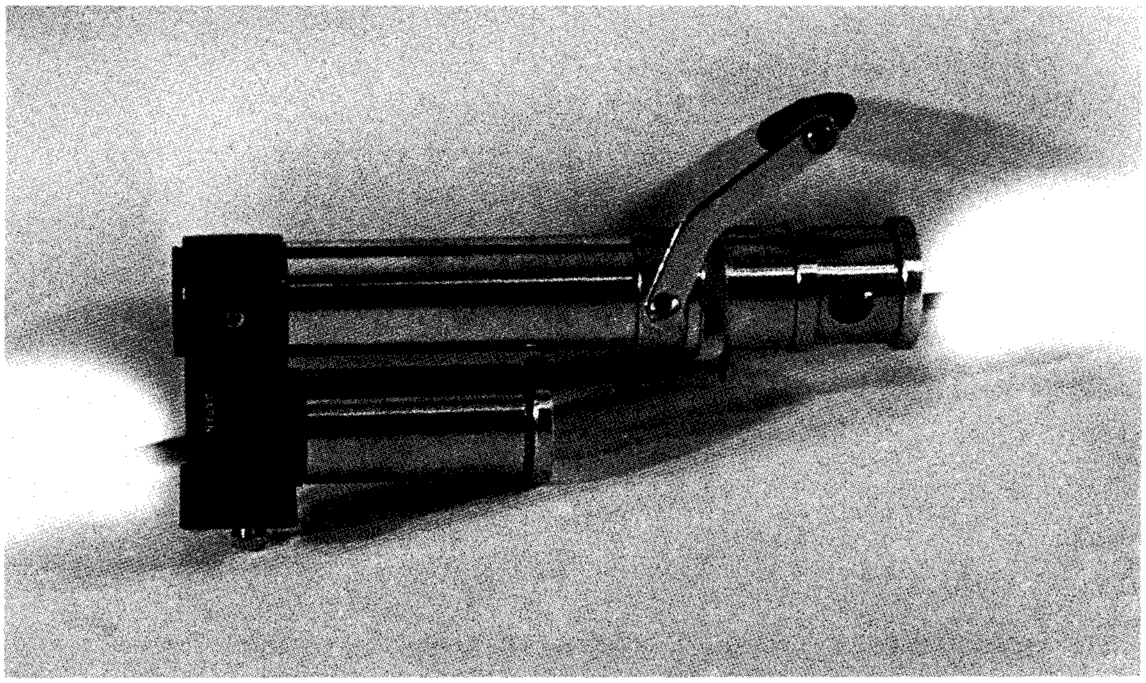
4. **Calibrate the diffraction gratings** for an accurate measurement of the lines present in atomic emission spectra. Use the sodium lamp as the light source as it emits an orange monochromatic light at 589 nm. Observe the first and second order images on both the right and left and hence calibrate the grating accurately. *For further details, refer to Year 12 Senior Physics Prac Manual, Experiment C8.*

5. **Determine the wavelength of the sodium light,** as a corollary to the previous experiment. If the grating value is accurately known, then the wavelength of the sodium line is easily calculated using much the same procedure as in the previous experiment. Note: the sodium line is actually 2 lines 0.5 nm apart, but it is almost impossible to resolve with this equipment.

6. **Observe and estimate the wavelength of the line spectra** emitted from various light sources, including the mercury vapour lamp, the neon spectrum tube and even the 'long-life' light bulbs. Compare the estimated values for the wavelengths with the published ones. *Refer to the colour plate on page* 14 *in the front section of Science for High School Students - most other texts also have information on the wavelengths of the common spectral lines.*

7. **Observe and measure the 4 emission lines in the visible region for hydrogen.** Set up the spectrometer with the hydrogen spectrum tube and diffraction grating. Allow students to participate in this exciting phase of historical scientific discovery as they verify the empirical formula for the Balmer series of spectral lines, first proposed in 1885 by J.J.Balmer.

SPECTROSCOPE



The hand spectroscope is a small instrument used to view and measure spectral lines from various light sources. Light enters through a single adjustable slit, is focused with a lens and then dispersed through a system of glass prisms to produce a spectrum of colours.

Most spectroscopes have two tubes, the longer one being the main viewing telescope, while the shorter one contains a scale which can be moved across the spectrum to calibrate it. The scale is graduated in nanometres, where 1 nm $= 10^{-9}$ m.

Some models come in a case with three miniature test tubes which can be filled with liquids and used to observe absorption spectra.

SAFETY PRECAUTIONS

- Handle with care – dropping this device could damage the intricate internal prism and lens structure.
- Do not permit students to look directly at the sun through this device, as the sun's rays will burn the retina of the eye.

SETTING UP AND USING THE SPECTROSCOPE

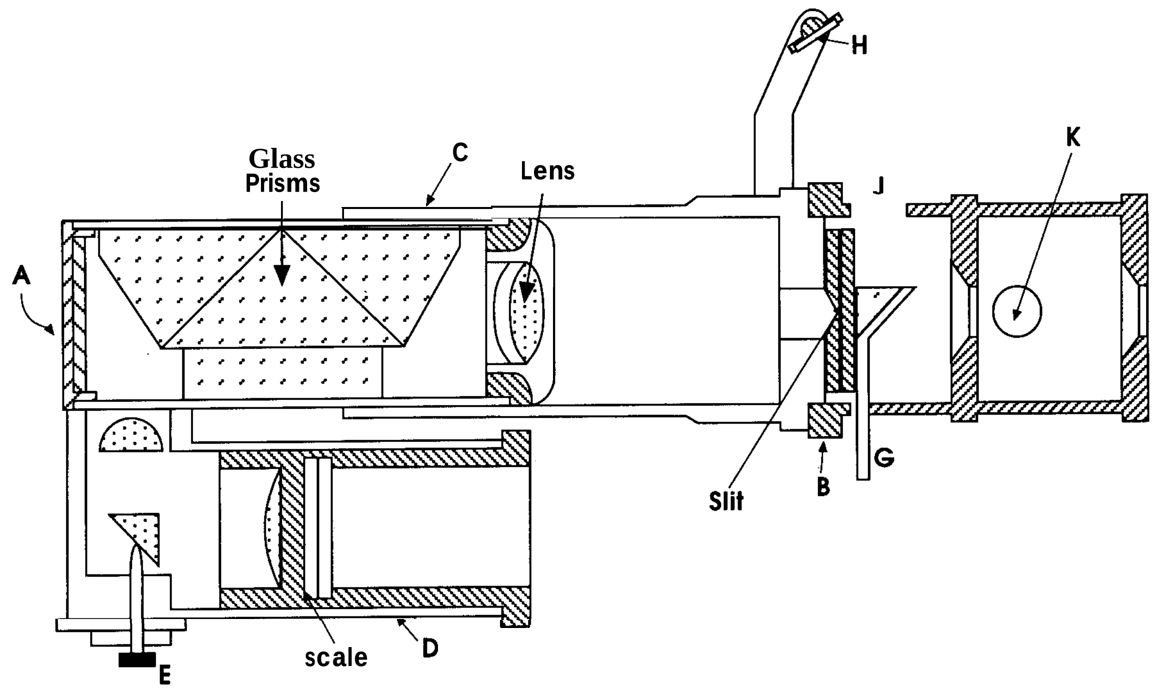
C **It is worth checking the following items before an experiment is set up**

- Ensure the spectroscope has not been dropped and damaged by testing to see if a white light spectrum is clearly visible. Follow the first two steps of the setting up procedure.

X **Extra equipment for the suggested learning experience (numbers refer to appropriate experiences) includes:**

- an ordinary light globe (tungsten filament) and desk lamp mounting (1, 4)
- a mercury lamp, mounting and power supply (2)
- a sodium lamp, mounting and power supply (2, 3)

- neon discharge tube and stand - see ***instructions for setting up spectral tubes on page*** 30 (2)
- a hydrogen discharge tube and stand - see ***instructions for setting up on page*** 30 (2)
- a power pack (2)
- an induction coil (2)
- 2 long leads with alligator clips, 2 with banana clips (2)
- nichrome or platinum wire with a glass handle (2)
- chlorides of sodium, calcium, potassium, strontium and barium (2)
- a piece of copper wire (2)
- concentrated hydrochloric acid (2)
- small beakers (2)
- coloured filters (4)



jigure 1

Setting up the Spectroscope

- Hold the spectroscope horizontal so that the long tube is on the right and the short tube is on the left. Lever (G) should be up.
- Look through the eyepiece (A) and observe the **solar** spectrum by directing the spectroscope at a bright part of the sky (not directly into the sun). The red should appear on the left and the violet on the right.'
- Adjust the slit size by turning the knurled ring (B) until Fraunhofer lines (vertical dark lines) become visible down the spectrum. The slit usually needs to be almost closed for clearest viewing.
- To focus the spectrum, slide the long tube (C) in or out until the Fraunhofer lines are clear. The tube does not generally need to be pulled very far out for focusing.
- To focus the scale, slide tube (D) until the graduations on the scale are clear. If it is difficult to actually see the scale, close the slit for this step.

- To move the scale, turn screw (E) until the marked 589 graduation exactly corresponds to the Fraunhofer 'D' line (the most conspicuous dark line in the orange region of the spectrum). The spectroscope is now calibrated and can be used to read off wavelengths from any spectrum being examined.

SUGGESTED LEARNING EXPERIENCES

1. **View a continuous emission spectrum** from an ordinary tungsten filament lamp following the same procedure as outlined above.

2. **View line emission spectra** in a darkened room using the following light sources :

   - the mercury lamp.
   - the sodium lamp.
   - the neon spectrum tube - *see instructions for setting up spectral tubes on page* **30.**
   - the hydrogen spectrum tube - see *instructions for setting up spectral tubes on page 30.*
   - the characteristic coloured flame of the following metals - sodium, calcium, potassium, strontium and barium. To create this light source, clean a nichrome or platinum wire by dipping it into a solution of concentrated hydrochloric acid and burn off any residue in a bunsen flame. Dip the clean wire into a small beaker of the chloride salt of one of the metals. Heat in a bunsen flame to obtain the characteristic colour.
   - the characteristic green coloured flame produced when a copper wire is heated in a bunsen flame.

   Estimate the wavelengths for each set of emission lines using the scale in the spectroscope.
   Compare your estimated values of these line spectra with documented values.
   Refer to the colour plate on page 14 *in the front section of Science for High School Students - most other texts also have information on the common spectral lines.*

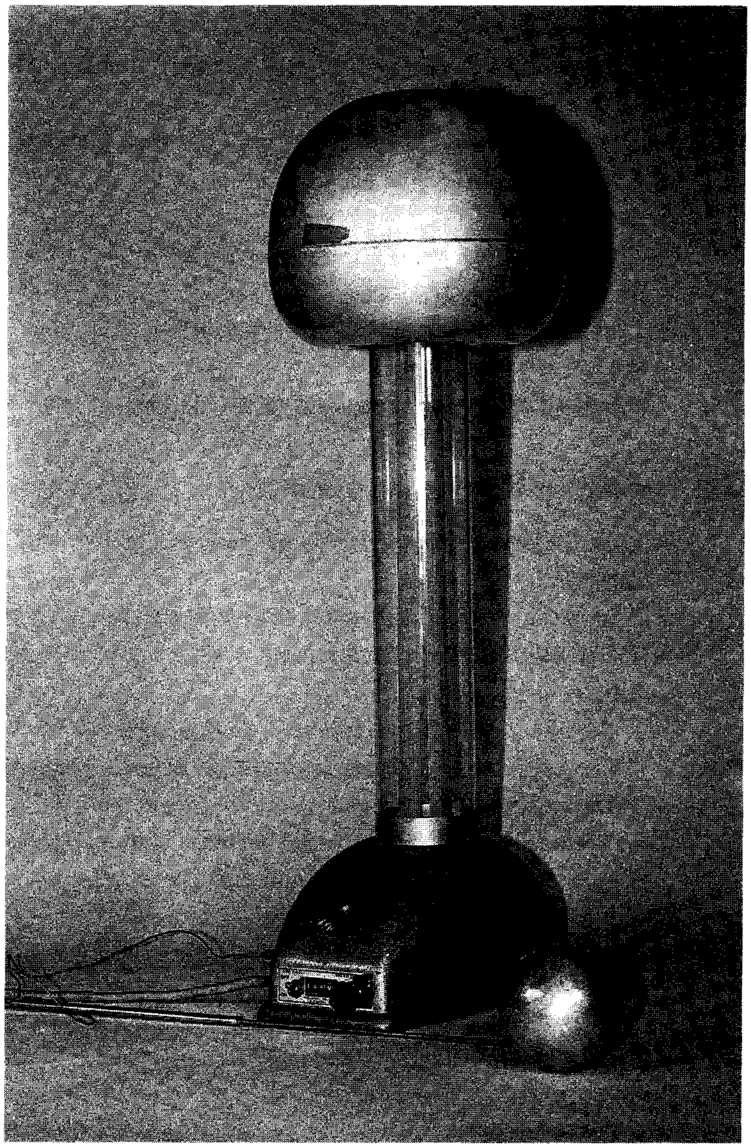
3. **View line absorption spectra** by :

- using the sun indirectly as a source of light and viewing the Fraunhofer dark lines. *Refer to the setting up procedure for details.*
- placing a sodium flame source between the sodium lamp and the spectroscope. The sodium flame will absorb particular frequencies of light which appear as dark lines in the spectrum. These bands correspond to those emitted initially by the sodium lamp.

4. **View band absorption spectra** by placing:

- coloured filters in front of an ordinary tungsten filament globe. Observe the dark bands where a larger range of frequencies are absorbed by the filter.
- a solution of potassium permanganate, chlorophyll, or one of the metallic chloride salts previously mentioned into a micro test tube. Insert the tube in hole (K) in front of the slit *(seefigure 1)* and use an ordinary tungsten filament light globe as a light source. The resulting spectrum can be compared directly with the white light source by moving lever (G) down. This moves a prism across half the slit. The top half of the field of view is now the absorption spectrum being examined, while the bottom half is the continuous emission spectrum from the tungsten filament lamp. The latter is very dull and can be brightened by adjusting the position of mirror (H) so that it reflects light into hole (J).

VAN DE GRAAFF GENERATOR



The Van de Graaff generator is a device which produces and stores a large electrostatic charge on a metal dome.

It discharges to a smaller sphere and, in ideal conditions, it can produce a voltage of 400,000 volts with a short circuit current of 20 micro-amps.

It can be used to demonstrate the presence and nature of electric fields and the functioning of the Van de Graaff Accelerator.

SAFETY PRECAUTIONS

- Take off all ***metal jewellery*** before handling the machine.
- Check that the discharging sphere is ***always*** the closest thing to the charged dome.
- Always hold the discharge sphere support rod by its insulating handle.
- Be careful not to touch the metal base of the machine when it is running.
- When switching off the machine, it is safer to use the switch at the power point.
- After switching off at the power point, always ensure the spheres touch together to earth the main dome before touching the machine with your hand.
- Though the Van de Graaff operates at high voltage, its low current assures that it is HARMLESS. Nevertheless, a shock from it can be quite unpleasant.

SETTING UP AND USING THE VAN DE GRAAFF

C **It is worth checking the following items before setting up an experiment**

- ***The functioning of this equipment is heavily dependent on weather conditions.*** The electrostatic charge leaks away rapidly to water molecules and dust particles in the air. Hence the equipment works most efficiently on a dry windy day.

- Set up the Van de Graaff at least 1.5 metres away from walls, light fittings, plumbing etc.
- Arrange to be in a laboratory which can be blackened out with heavy blinds or in a large dark room. In this way, the full array of the discharging spark can be seen.

X **Extra equipment for the suggested learning experiences (numbers refer to appropriate experiences) includes:**

- clean dry cloth
- sticky tape (2,4)
- a perspex and ebonite rod and a piece of silk and flannel (2)
- small pieces of paper (2)
- a wig, or one made from long strips of paper or wool attached to the top half of pantyhose (2)
- 4 petri dishes (4)
- paraffin oil or baby oil (4)
- a beaker of small grass seeds eg. couch (4)
- tin foil or metal hooks (4)
- 2 long leads with alligator clips attached (4)
- an overhead projector (4)
- a large foam ball suspended on a nylon thread (2)

S **Setting up the Van de Graaff**

- Wipe the dome, the sphere and the perspex column with a clean dry cloth to remove any dust particles.
- Plug in the machine and, using the black knob on the base, adjust the speed to a maximum.
- Touch the dome with the discharging sphere and build up the capability of the machine in the following manner:-
  - Position the discharge sphere just a few millimetres away from the charging dome and wait till there is a regular steady discharge of approximately one per sec.
  - Increase the distance and repeat the procedure.
  - The rate of discharge is a better indicator of the performance of the machine than the optimum voltage, because the optimum voltage is affected so greatly by the conditions of the atmosphere.
  - Leave the machine running, discharging regularly as described above, for 5 - 10 minutes before doing any experiments.

HANDY HINTS

The performance of the Van de Graaff improves with frequent use.
Dry out the rods, cloth and wig in the oven before use.
On humid days, while the machine is warming up, leave on a radiator close by.

SUGGESTED LEARNING EXPERIENCES

Topic - Electrostatics

1. Develop the concepts of charge, current and voltage.

This is a set of experiences to motivate students and familiarise them with the concepts of static charge being built up on an object and voltage being a measure of the electric potential energy.

- Darken the room.
- Observe the intensity of the spark as the spark gap changes -the bigger the gap, the more energy

is required for the discharge to occur, and therefore the bigger the voltage.

- Observe the intensity of the spark as the speed of the motor is changed.
- Observe the intensity of the spark and the change in the motor speed as the charge is allowed to build up over time – it gets harder for the charge to be received by the dome.
- Turn the machine off at the power point and observe the discharge.

2. **Discover the interactions between like and unlike charges.**

This is a set of learning experiences to demonstrate the nature of the electrostatic force and the presence of the electric field.

- Leave the charge to build up on the dome and allow students to experience the electrostatic pull on the discharge sphere as it is held about 10cm from the dome. Also experience the push of the repulsive force as the dome discharges. Repeat at different distances and at various charging times.
- While the machine is turned off, fasten a wig, or a collection of small strips of paper on to the dome. Turn on the machine and observe the repulsion of the similarly charged strands of hair or paper. Discharge the dome and note the effect.
- Alternatively, encourage students with long, fine hair to stand close to the Van de Graaff while it is charging. Do not stand closer than the discharge sphere.
- Charge a large foam ball connected to a long nylon thread by touching it with a charged ebonite rod. Suspend the ball close to the dome of the Van de Graaff and observe the effect. Repeat using a perspex rod and determine the type of charge produced on the dome.
- Keeping the discharge sphere at the maximum range (10-15cm), drop a handful of small pieces of paper between the dome and the sphere and observe the behaviour of the paper. This is powerful evidence for the presence of an electric field.

3. Develop the concept of ionisation.

- Darken the room. Demonstrate the corona effect from the pointed end of the discharge rod as the surrounding air particles become ionised.

4. Clarify the nature of electric fields.

Use the Van de Graaff generator as a high voltage source of electricity to map the electric field around differently shaped electrodes. See *Exp.* 9.4 *in Essential Physics or Exp E.5 in Senior Physics Year 11 for details of the procedure of the experiment.*

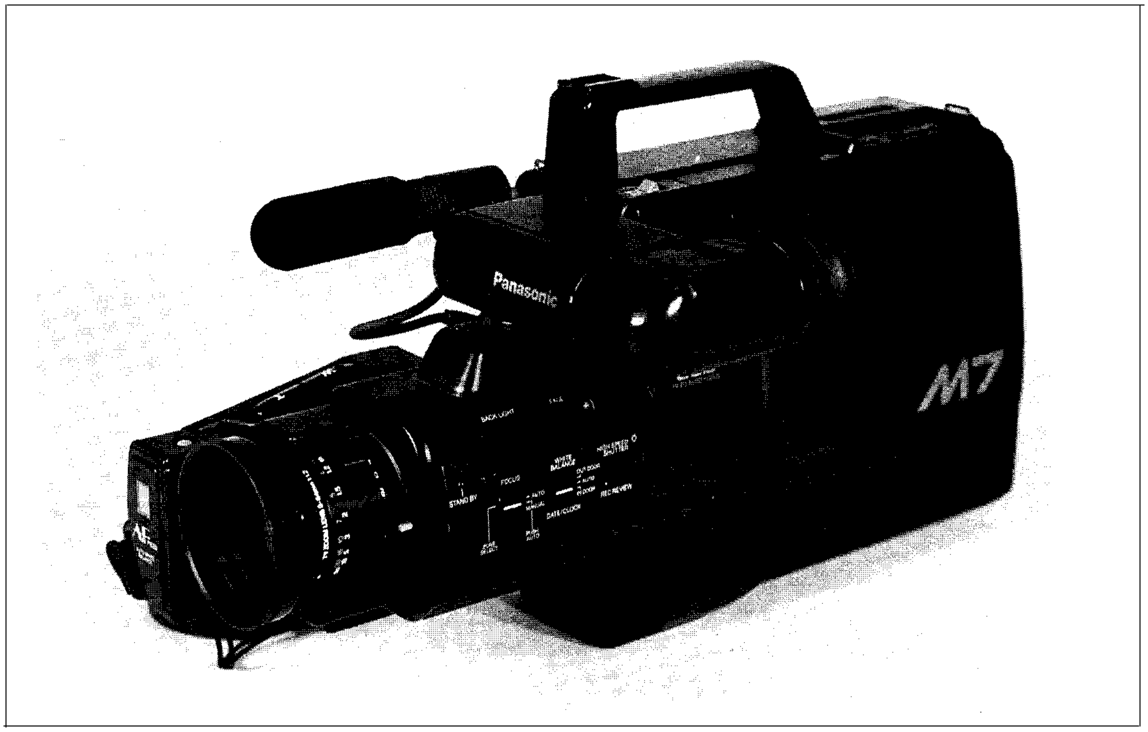
- connect the stripped end of a wire to the dome with sticky tape.
- disconnect the discharging sphere and use this earth wire to connect to the other electrode.
- place a petri dishes with oil in them on the overhead projector so that all students can see the results clearly.
- sprinkle the seeds into the petri dish *just before you* start the demonstration as the seeds will absorb the oil and eventually sink to the bottom.

Topic - Nuclear Physics

5. Discover the principle of the functioning of the Van de Graaff Accelerator.

Take the Van de Graaff generator apart and show students how it works. Explain similarities to the accelerator.

VIDEO CAMERA



The use of the video camera to record events and to provide clear and reliable information for analysis, is far superior to other photographic techniques.

It has always been difficult to record the motion of objects during experiments. One tried and true method is to use black and white polaroid film to take stroboscopic photographs. The film is available within minutes but, due to the small size of the photographs, analysis is difficult.

On the other hand, the video camera provides results which can be easily measured and are accessible to every class member.

SETTING UP AND USING THE VIDEO CAMERA

C **it is worth checking the following items before an experiment is set up**

- If you are unfamiliar with the working of a video camera, check the instruction booklet which comes with it. ***Allow*** *an hour or more to familiarise yourself with the camera.*
- Make sure you have a new battery or a fully charged extra battery for the camera.
- Ensure that you have the correct connecting leads to go from the camera to the TV monitor and from the VCR to the TV monitor.

X **Extra equipment for the suggested learning experiences includes:**

- VCR with still frame and frame advance
- a television set, with appropriate connections for the VCR and the camera.
- a blank video tape
- a blank overhead transparencies
- a meter rule
- paper and texta to make introductory annotations
- an overhead projector
- a timing device eg. a stopwatch, venner clock, radiation scaler or digital clock.
- a piece of black material to be used as a backdrop

Setting up the Video Camera

- Connect the VCR to the TV and check its functioning.
- Set up the experiment which is to be recorded in a position with good lighting - the overhead projector can be used as a strong source of side lighting.
- Use the black material as a backdrop to obtain a good contrast.
- Place the meter rule and timing device (*see above*) in the field of view.
- Prepare annotations to identify the event, the students, the date etc.

HANDY HINTS

- The video camera and television can be used to enlarge the results of almost any experiment, to make it easily observable by the whole class. For example, a video set up to view a cathode ray oscilloscope will display a much larger version clearly on the TV screen. This will make small-scale experiments, such as the mass of the electron kit, a more practical alternative for the classroom. In order to set this up, connect the video camera directly to the TV monitor and the event will be enlarged on the spot.

SUGGESTED LEARNING EXPERIENCES

Video cameras can be used to record and analyse many different events - particularly those in topics of motion, forces and collisions. In each case the procedure, as outlined below, will apply.

- Record the event on the video camera.
- Play it back through the view finder and check that the recording is suitable.
- If it is not suitable, re-record.
- Several events can be recorded quickly, incorporating changes to velocity, slope, mass etc. giving a related group of results.
- Use the inbuilt microphone to record comments and useful information.
- View the event(s) played back through the VCR and TV.
- Fix a blank overhead transparency to cover the TV screen.
- Trace the meter rule on to the overhead transparency.
- Using the still frame and frame advance of the VCR, go through the motion step by step, marking the positions of objects on the overhead transparency.
- Take a note of the time interval between the steps using the timing device displayed in the experiment
- Project the transparency on to large sheets of paper OR
- Photocopy the transparency so that each student can analyse the results.

This procedure can be used for the following experiences:

1. **Motion in one dimension along a linear air track**
2. **Motion in two dimensions on air or bead tables**
3. **Projectile motion**
4. **The motion of falling objects**
5. **Circular motion**
6. **Simple harmonic motion**
7. **Collisions using trolleys**
8. **Collisions on the linear air track**