

Chapter 2 - SENSING

2.1 Activity 10D: Demonstration Logging the Lab

Requirements

Data logger with many sensors (for example: microphone, thermometer, potential divider indicating angle of door to room, light dependant resistor with potential divider)
Large display from data logger, perhaps computer and monitor

Practical Advice

This is one of several possible engaging quick introductions to the idea of instrumentation.

The idea is that as students come into the lab, they find that it is 'wired up', logging data continually. For example, sound levels, light levels, temperature might be monitored. As the class quietens down the sound level drops, but the temperature may start to rise.

If a multi-channel data logger is not available then adapt either several single channel data loggers, with different sensor or use traditional demonstration instruments, with large visual outputs, such as an oscilloscope for the microphone, and demonstration voltmeter (0–5 or 0–10 V f.s.d.) for the potential dividers.

As students enter the lab, set the data logger (or other monitoring equipment) to run and display while students arrive. The teacher might encourage students to speak into the microphone, to grab hold of the thermistor, or to shield the LDR from light. Perhaps students could walk through a light beam illuminating a photodiode.

Imaginative use of other sensors is to be encouraged: humidity, oxygen level (breathe on these), pressure (squeeze a bicycle pump with sensor sealed in), strain gauges (bend a clamped metal ruler), u.v. or photovoltaic (aim the detector at the Sun). All are readily available. All would make the point that changes in the environment can be detected and converted into information in electrical form, usually a potential difference, which can then be usefully recorded and used.

This introduces sensors in a lively way, and can start interesting discussion: what are sensors? what sorts of thing do they do? how do they do it? how can we make use of the information that they generate? why might they be important to society?

The discussion could naturally be extended to the concept of a 'smart house' that could respond to changes in conditions. Start a fan if too hot, a heater if too cold, close blinds if too bright, lights on if too dark, start fan if air is stale, close door if too draughty etc.

Other possible uses of sensors can be discussed, in this and wider contexts such as: sensors on a space craft, an industrial robot, or in an incubator for premature babies. Teachers should feel free to develop their own alternative introductory strategies.

Many seeds of the themes of work on instrumentation can be sown in this introduction: the range of sensed voltage, the resolution of signals, the sensitivity and response time of sensors, the information that is generated and how it might be analysed, smoothed, averaged and graphically represented. It should be an engaging and enjoyable experience.

2.1 Activity 20D: Demonstration Current and charge in electron beams

Requirements

Electron deflection tube
EHT power supply, 0 – 5kV d.c.
2 demonstration digital multimeters
leads, 4mm

Practical Advice

This demonstration shows how electron currents can be made to flow through a vacuum tube and show some properties of the beam. These are charge and energy flow and electric deflection by charge distributions within the tube.

These notes assume an electron deflection tube is used. If this is not available then a Maltese cross tube does just as well.

Start by explaining the action of the electron gun, as the circuit is built up. The filament is run from the standard 6.3 V a.c. connection on the EHT supply. It glows white hot.

The thermionic emission from the hot cathode creates a space charge around the filament (electrons 'boil off' the filament and surround it).

The electrons can be accelerated towards the anode if it is made positive with respect to the cathode. The filament is connected to the negative EHT terminal (usually earthed). Some electrons hit the anode and return to the EHT supply. This current can be monitored with a milliammeter in the return wire.

As the p.d. is increased to a few thousand volts, some electrons travel across the vacuum to hit the screen and make it fluoresce. The larger the voltage the more the kinetic energy gained by the electrons and the brighter the fluorescent screen glows.

If the polarity of the EHT is reversed there is no beam or fluorescence at the screen. This diode action shows that the moving charge in the beam is negatively charged. NB: switch the power off before changing the connections to avoid unpleasant shocks.

Electric deflection of the cathode rays is demonstrated by connecting a second EHT supply across the deflection plates.

Technician's note: The demonstration is more effective in a darkened lab, with control of the room lights as the circuit is built up in stages.

Alternative Approaches

A variety of vacuum tubes could suit this purpose. If the demonstration is performed with a Maltese cross tube, the filament glows white hot, casting a shadow of the cross on the front of the tube (light travels in straight lines), the electron beam also casts a linear shadow, corresponding to the light shadow, showing that the electrons also travel in straight lines here.

Electric deflection of the cathode rays is easily demonstrated by turning down the EHT and disconnecting the cross from the anode. By letting it float electrically the incoming electron beam will start to charge negatively and to repel the electrons in the beam. The fluorescent Maltese Cross shadow swells to the form of a four-leaf clover, but the light shadow remains unaffected. The effect becomes greater as the gun voltage is increased and the cross charges to a higher equilibrium potential with more charge on it.

A variety of vacuum tubes could suit this purpose. If the demonstration is performed with a deflection tube, a separate EHT will be required to run the deflecting plates. The fine beam tube although giving the opportunity to visualise the beam through low pressure gas ionisation, cannot easily show electric deflection. Magnetic deflection of the beam is premature at this stage.

2.1 Activity 30D: Demonstration ‘Spooning’ charge

Requirements

Digital coulomb-meter

Plastic rods, polythene and acetate or perspex with cotton cloth

EHT power supply, 0 – 5kV d.c.

Metal disc on 4mm plug

Leads 4mm

Teaspoon and tablespoon each mounted on insulating polythene rods

Practical Advice

Here we demonstrate how charge can be spooned around, as if it were like sugar or milk. Using a teaspoon and a tablespoon on insulating handles helps to dramatise the point. Of course, any conductor will do. The aim is to cement the idea of charge as like a quantity of transferable, if invisible stuff. Charge here is simply measured by a coulomb-meter, treated as a black box.

Successive spoonfuls are transferred from a plate connected to the 5 kV supply at say 2000 V to the coulomb-meter, and may be summed by the meter and averaged for 10 spoonfuls. The larger spoon, of course, carries more charge (sugar); successive 'spoonfuls' transfer equal increments of charge (provided that the coulomb-meter has an input capacitance large compared to that of the spoon).

It is worth demonstrating:

- Transfer of positive charge (removal of electrons from the spoon) by earthing the negative terminal of the 5 kV supply and taking charge from the positive terminal at about +2 kV.
- Transfer of negative charge (adding electrons to the spoon) by earthing the positive terminal of the EHT supply and taking charge from the negative terminal at about –2 kV.
- Increase of charge transferred when the potential difference is increased
- Increase of charge transferred when a larger spoon is used.

It is useful to include also simple demonstrations of charging polythene and Perspex or acetate rods by rubbing with a cloth. Emphasise here the stripping of a tiny fraction of the electrons present off one material onto the other.

Some teachers may want to introduce the idea of capacitance here (even though it is in the A2 part of the specification). If so, double the potential difference of the 5 kV supply to 4000 V, and show that the charge transferred per spoonful doubles too, for both spoons. From this proportionality we can then naturally define the capacity of the spoons to hold charge:

capacitance = charge / potential difference

$$C = Q / V$$

For example, 10 spoonfuls of a tablespoon transferred 70 nC at 4 kV. The capacitance is $C = 7 \text{ nC} / 4 \text{ kV} = 1.8 \text{ pF}$.

Alternative Approaches

If the 5 kV supply is not available it is possible to do the demonstration with a Van de Graaff generator, but its potential is much more variable and the results less convincing. Similarly, a calibrated gold leaf electroscope can be substituted for the digital coulomb-meter. If the Van de Graaff is used the belt and combs need to be checked, and the machine tested on the day for charge production. A hair dryer helps operation on damp days when charge leaks to earth nearly as rapidly as it is produced.

2.1 Activity 40D: Demonstration Shuttling balls and ions in flame

Requirements

EHT power supply, 0 – 5kV d.c.

Pair of conducting discs, insulated and clamped vertically

Leads, 4mm

Colloidal graphite coated table tennis ball suspended on 1.5m of nylon monofilament

Tall retort stand, boss and clamp

Microvoltmeter

Stroboscope

Candle and matches

Practical Advice

A Van de Graaff generator may be used instead of the 5 kV power supply. Ensure that the galvanometer is earthed and that no sparks jump to it. Start with the plates close enough together (about 6 cm apart) for the ball to shuttle automatically. If the stroboscope is to be used to measure the frequency of movement of the ball, the laboratory needs to be darkened.

It may be helpful to have the whole of the plates and the retort stand on a large sheet of insulator, to permit rotation of the whole apparatus in order to allow the entire class a clear view of the volume between the plates.

Here the emphasis is on current as a flow of charge with a visible carrier in the form of a shuttling ball, and then as ions in a flame.

A graphite painted table tennis ball (use colloidal graphite paint) is suspended on a 1.5 m of insulating nylon thread, suspended between two metal plates held on insulating rods about 6-8 cm apart. The dome of the Van de Graaff generator is connected to the nearest plate, and the far plate is earthed to the base of the generator. The ball shuttles between the plates and charge is clearly set in motion. The frequency of shuttling can be increased by increasing the potential difference (faster motion of belt, or increased output from EHT supply), or by moving the plates closer. The current can be measured by placing a sensitive light beam galvanometer in the earth return circuit. The meter indication shows that a moving charge constitutes an electric current. The direction of the charge flow and the sign of charge on the generator dome can be found. Such a galvanometer has a typical sensitivity of 25 mm / mA, and a current of a few mA can usually be achieved.

A stroboscope can be used to find the frequency of shuttling. It is important to freeze the motion at one end rather than the middle to avoid visual aliasing (increase strobe rate until two images of the ball, one at each plate, are seen and then drop to half this rate).

A number of calculations are worth doing:

- Number of coulombs flowing per second
- Number of electrons flowing per second
- Charge on the ball (typically about 10 nC)

The demonstration can be completed by replacing the shuttling ball with a candle flame, and measuring the ionisation current carried by the ions in the hot gases of the flame. The current from the ions in the hot flame will conduct a current several orders of magnitude larger, so the sensitivity of the galvanometer will need to be decreased to measure current of the order of milliamperes. The ions are produced in oppositely charged pairs from the originally neutral candle wax. The C⁺ ions responsible for the brightness of the flame will be attracted to the negatively charged plate and will deposit as carbon black when they hit the plate and become neutralised.

Alternative Approaches

The slow but visible movement of coloured ions as current carriers is a good alternative. The ionisation current in a miniature neon indicator lamp taken above its striking voltage (about 60 V), could also be demonstrated, using an EHT supply and suitable 50 mA meter.

2.1 Activity 50D: Demonstration Conduction by 'coloured' ions

Requirements

Power supply, 0–150V d.c.

2 demonstration multimeters

1 M ammonium hydroxide solution (Aqueous ammonia)

Microscope slide covered with filter paper soaked in ammonium hydroxide solution

Small crystals of copper sulphate and potassium permanganate

2 pins to use as connectors

Crocodile clips

Stop-watch

Tweezers

Practical Advice

Here we demonstrate that electric currents involve the slow but perceptible movement of coloured ions carrying a current linking current to flow of charge.

The drift velocity of less than a millimetre per minute (about 0.01 mm s^{-1}) is surprisingly slow. It should be contrasted with the rapid propagation of the electrical signal that travels around the circuit, telling the charges to get moving, when the circuit is switched on.

The filter paper is held onto the glass slide by the surface tension of the ammonia solution, which should be added by pipette just prior to the demonstration, and by the bulldog clips, which should be only a couple of centimetres apart to increase the electric field and the drift velocity. Small single crystals of blue copper sulphate and purple potassium permanganate should be placed using tweezers, midway between the pins. Very slow symmetrical diffusion of the coloured ions can be observed.

The d.c. supply should be switched on at 30 V and the stop-watch started. The current measured will typically be in the range 10–100 mA. If the coloured patches are carefully observed over several minutes, the slow asymmetrical drift of the deep blue positively charged cuprammonium ions (Cu^{2+} complexed with ammonia) towards the negative electrode, and of the purple negatively charged permanganate ions (MnO_4^-) towards the positive electrode, can be observed. The invisible ammonium and hydroxide ions also contribute to the current. After several minutes of observation the distance and time can be measured and the drift velocity calculated (a control with no electric field could be run to estimate the diffused distance in the same time, and subtract it).

The drift velocity will be around 0.01 mm s^{-1} . The different mobilities of the two ions may be apparent if the experiment is run for many minutes. If the terminals are reversed, then the motion of the coloured ions can also be reversed. The permanganate may become oxidised in the air leaving a brown stain of manganese dioxide on the paper.

It is worth finding the conductance of the medium, mostly the ammonium and hydroxide ions on the paper, from the values of current and potential difference.

A carefully constructed cell for use with the power supply, 0–150 V, is used to provide rapid movement and a safe demonstration. If no such cell is available then lower p.d.s should be used.

Technician's note: the filter papers should be cut into rectangular strips to fit the standard microscope slides and held in place with the pins and crocodile clips. The ammonia solution needs to be strong enough to form the deep blue cuprammonium complex. 1 M should suffice, but it should only be pipetted onto the paper immediately prior to the demonstration. Only a very small quantity is required. Spare slides should be prepared to repeat the demonstration or to act as a control without the applied potential difference.

Alternative Approaches

If you have access to higher p.d. power supplies then somewhat more rapid ion movements can be seen. But be aware that you should not have bare wires above 30 V on the bench. A carefully constructed cell for use with the power supply, 0–150 V can provide rapid movement and a safe demonstration. The cell must have interlocks to prevent access when a voltage is applied.

Conduction by ions in a neon indicator lamp can be demonstrated, above the striking voltage. This is a nice example of a non-ohmic conductor and the V / I characteristic can be plotted with a data logger, if a 10:1 potential divider is used to reduce the voltage logged.

2.1 Activity 110E: Experiment Using the digital multimeter to measure resistance

Requirements

Clip component holder
Selection of resistors
4mm leads
digital multimeter

Practical Advice

This is a very simple experiment for early stages in understanding. However, students should get used to handling the ranges of the multimeter. The experiment also introduces them to errors. Working with a large batch of resistors produces a more striking effect (ideally at least 100). Obviously the measurement will become very boring with large numbers of resistors so use a group of students and put the results onto a spreadsheet to eliminate the repetitive calculations. The statistical side could be taken further by plotting a frequency distribution graph and looking at standard deviation.

Resistors to select from:

- Resistors from different ranges, e.g. 560 Ω , 1000 Ω , 4.7 k Ω , 68 k Ω , 330 k Ω , 2.2 M Ω , 10 M Ω labelled for convenience. (If you mask the values, provide an answer card with values printed against labels used)
- Each student should be given a large number of resistors of the same resistance and tolerance, e.g. 22 k Ω and 5% tolerance.

Alternative Approaches

Any simple experiment can be used to show random errors and the advantage of averaging readings.

2.2 Activity 70D: Demonstration Speed of pulse on coaxial cable

Requirements

Pulse generator, 200 kHz
Coaxial cable on drum, 200 m
4mm leads
single pole switch, mounted with 4mm sockets
Oscilloscope or PC-scope

Practical Advice

This demonstrates how the currents in a circuit get going. After having seen the rather slow drift velocity of coloured ions carrying charge in an electrolyte, it is useful to see the rapid propagation of electrical signals around circuits. There is no apparent wait for a light to come on once the switch is turned on, other than the warming-up time of the filament. Certainly electrons from the switch would take many minutes to reach the bulb travelling at their drift velocity in a d.c. circuit. The measurement of the near light speed for signal propagation is exciting and instructive.

The demonstration uses a 200 kHz pulse generator and a 200 m drum of coaxial cable. The PC-scope will need to be able to resolve times down to a few microseconds. The outer conductor of the coax is grounded to shield the signal pulses applied to the inner conductor. A fast single beam oscilloscope connected across the near end of the coaxial cable can trigger on the pulses, 5 ms apart. The frequency of the generator can then be calibrated against the oscilloscope timebase. Reflections from the far end on open circuit return attenuated with the same phase. With the far end shorted (inner and outer conductors connected by a switch) the phase is inverted on each reflection. The transit time for one or more reflections can be used to find the speed of the electromagnetic pulse down the coaxial cable (it is rather slower than light speed since it is travelling in the plastic insulator of the coaxial cable and not in a vacuum).

Technician's note: 4 mm connectors on connecting leads need to be soldered onto the inner and outer conductors of the coaxial cable, at both ends, prior to the demonstration.

Alternative Approaches

If the far end is terminated by a cable impedance matching 68 Ω resistor, the reflections are absorbed at the far end and little signal echoes on the line. With this arrangement, a double beam oscilloscope can be used to look simultaneously at the pulse as it goes out and as it arrives at the far end.

As an optional extra demonstration, the speed of a human reflex signal could be observed or timed, using the classic knee jerk response. The propagation of such nerve impulses depends on ionic pumps in cell walls driving Na^+ ions out through the nerve cell membranes. Here p.d.s of around 70 mV can be produced across the membrane and propagate down the nerve cell. However, this signal does not propagate at light speed, being limited by the response of the ion pumps in the cell membranes. However, this signal is not an electromagnetic wave but a 'chemical wave' of activation of successive pumps along the nerve fibre.

2.2 Activity 60E: Experiment Conduction by students

Requirements

Power supply, 5 V d.c.

Microvoltmeter

4mm leads

Class of student volunteers

Practical Advice

Here we demonstrate that students conduct electric current, albeit in small quantities if the voltage supply is low. Conductance can be defined, measured and compared to the more familiar reciprocal quantity resistance. This is intended to be a straightforward, quick, fun demonstration to introduce conductance.

Make a series circuit with all the (willing) students clasping hands, a 5 V d.c. power supply and the galvanometer, measuring the unfelt current around the complete loop. The current will depend on many factors including dryness of students' skin. Typically for a ring of ten students currents are around tens of mA, so the galvanometer will need to be set at an appropriate sensitivity.

To calculate the total conductance, divide the current by the potential difference. To calculate the conductance of per student, first divide the potential difference by the number of students. Typical values for one person are about 30 kW or 33 mS.

If any pair of hands breaks contact the conductance falls swiftly to zero and so does the current. Students enjoy the effect of this on the light beam galvanometer, which is easier to observe in a partially darkened lab. Individual conductances can be measured, and are the basis for some lie detector tests (if you sweat when you lie)! Students may be surprised that they cannot detect currents at this level, and useful discussion about electric shocks, cardiac arrest, fibrillation and defibrillation can follow.

The variable contact conductance and the possible excitement of the students mean that their conductances are not constant enough to perform the obvious follow up. This would be to connect students in parallel and show that their conductances add, although it might be fun to try. This would have to be demonstrated with fixed conductors.

It is worth reminding students that the energy of chemical reactions and cells is relatively modest, being typically 150 kJ per mole. This translates to a few electron volts (eV) per electron. So the potential energy per coulomb for typical chemical cells is 1 or 2 volts.

Cells give electrons a rather low energy, but can produce substantial flows of charge by reacting chemicals in largish numbers of atoms per second. If a cell produces a current of 0.2 A it produces $n = I / e = 0.2 \text{ A} / 1.6 \times 10^{-19} \text{ C} = 1.3 \times 10^{18}$ electrons per second.

This is a very large number, but is only a small fraction of a mole, so cells can produce quite large charge flows over substantial times before their chemicals are all reacted.

Alternative Approaches

A more formal class practical could be run using resistance substitution boxes and a digital multimeter and calculator to bring out the relationships between conductance and resistance.

2.2 Activity 120E: Experiment Resistors in series and parallel

Requirements

A set of resistors marked with the letters A through to E
3 clip component holders
4mm leads
digital multimeter

Practical Advice

Each group requires access to a set of five resistors (Two of the resistors should have the same nominal value and come from the same batch.) Suggested values A = 300 kW, B = 100 kW, C = 75 kW, D = 150 kW, E = 100 kW (For a large group of students a few sets will be needed).

Technician's note: The resistor values are guides only and designed to make the 'sums' easier. Masking the resistor values stops students taking short cuts. However, for this experiment, working to 2 significant figures is appropriate for the purpose. Make sure the batteries in the multimeter are reasonably fresh.

Students may need help using the multimeter if this is their first attempt.

Alternative Approaches

The standard circuit for measuring resistance can be used with a power supply, ammeter and voltmeter. However, using the multimeter provides a quick method with fewer things to get in the way, especially for inexperienced students.

2.2 Activity 150E: Experiment Electrical characteristics

Requirements:

Coil of Constantan wire, 0.4mm (28 S.W.G.)

Clip component holder

4mm leads

Heatproof mat

2 digital multimeters

Power supply, 5 V d.c.

Rheostat

Additional apparatus for experiment 2: Carbon film resistor

As above substituting for the coil with a 100 Ω carbon film resistor in a clip component holder

Additional apparatus for experiment 3: Filament lamp

Filament lamp 12 V, 24 W

Power supply, 0 – 12 V d.c.

Additional apparatus for experiment 4: Silicon diode

Diode – 1N4001 (NB: max current 1A) with a protective resistor - 50 Ω or greater

Microammeter – to explore the reverse bias

Additional apparatus for experiment 5: Thermistor

Rod or bead thermistor

Protective wire wound resistor 10 Ω or greater

Practical Advice

Where you start on this activity depends on the experience and confidence of your students. The characteristics of the wire/resistor and the filament lamp are now part of many GCSE specifications.

You can divide the further experiments up amongst groups of students. Each group can then produce the graph, research the behaviour of the component to explain the characteristic and then give a presentation to the rest of the class. Photocopies of the graphs can be distributed to members of the class.

If you have already introduced the potential divider then the experiments provide good practice in its use. Encourage students to use the higher range from a meter, selecting more sensitive ranges when they have an estimate for the highest reading. Digital meters are more robust, easier to read and even the 0–10 A scale is reasonably sensitive. If you do have to use moving coil instruments you will need to check that the meter is correctly inserted in the circuit and the range is suitable. Experimental data and graphs on I / V characteristics of a filament lamp, a neon lamp and a silicon diode are on the CD-ROM.

Technician's note: the sizes of the potentiometer and ranges are indications only. It may be necessary to run through the experiment yourself to make sure your components and meter ranges are compatible.

Alternative Approaches

These experiments can be easily adapted for datalogging and the graphs drawn automatically by the software, e.g. Insight.

Similarly results obtained manually can be keyed into a spreadsheet package such as Excel or Insight and the graphs obtained. These spreadsheets will give an analysis of the shape of the graph.

2.2 Activity 130D: Demonstration Lamp lighting

Requirements

Filament lamp, 12 V, of various nominal powers, 5W, 24W, 36W, 48W, 100W

2 demonstration multimeters

Hand held stop watch

4mm leads

power supply, 0 – 12 V d.c. and a.c., 6A

Practical Advice

Strategy

This demonstration can be varied according to students' background in electrical power from GCSE.

Basic introduction

Show with a quick demonstration that power dissipated is given by the product of current and voltage ($J/s = C/s \times J/C$), energy, time, current and voltage being measured separately, observing the different brightnesses of the lamps. Nominal power ratings can be checked, and also the calibrations of the meters against each other. Discrepancies will almost certainly be apparent, and this can lead to good discussion on calibration and standards.

- Some joule meters can be used in power measuring mode, so that $P = I V$ could be checked directly for the series of lamps. Again, nominal values and agreement of meter readings can be checked. This might be appropriate for students who already have a secure grasp of power as rate of transfer of energy.

- A discussion of joule heating formulae can develop

$P = I V = V^2 / R = I^2 R$. This is a good exercise in thinking about constants and variables. It seems to many students that power is simultaneously proportional and inversely proportional to resistance! They could be challenged to explain this apparent paradox.

- For higher level students a study of the design of filament dimensions for a series of bulbs is very instructive (see Extension below).

The demonstration

The joule meter runs from its own mains supply, most being based on a solid state current-voltage multiplier. The output from this can drive either an external meter (watt meter mode), or can supply a train of pulses at equal energy increments which are fed to a mechanical or digital display, providing a direct indication of the energy dissipated (joule meter mode). A d.c. supply is preferable, but a.c. can be used.

Connect a shunt to the joule meter so that it will measure in joules connected to the input of the joule meter. It is adjusted to 12 V across the lowest power lamp, connected in the load circuit, with the series ammeter. The low voltage supply is switched off, the joule meter is reset and the stop-watch started as the supply is switched back on. The steady current is measured, and at the end of a suitable time interval (100 s makes easy arithmetic), the 12 V circuit is switched off again and the joule meter is read.

The power can be calculated from E / t , and can be compared to the product $I V$ and to the nominal power rating of the lamp. The joule meter does place a load on the external supply, but this is small and becomes less significant as the higher power lamps are used. Students should be invited to note the brightness of the lamp, and to record readings in a suitable table.

In the table given, all the lamps were switched on for 100 s and the potential difference across them

maintained at 12 V d.c. A variety of points can be discussed: the link between power and brightness, the tolerance of batch-manufactured items like these filaments and the reliability of calibration of the meters used. With no circuit connected, the joule meter used here recorded an output of about 50 J in the 100 s interval, so there is systematic error present in these data. One source of error is the averaging process of the meters. The d.c. output is not smooth and the meters take some sort of mean level.

Extension (for better students)

Challenge students to consider the relative dimensions of the filaments needed to achieve different lamp powers for the same potential difference. This is a good opportunity to show the power of algebraic thinking. Challenge them to find the relative dimensions of the filaments of the lowest power bulb and one ten times greater (say 5 W and 50 W).

Assumptions about the filaments would be:

- made from the same material, usually tungsten because of its high melting point (3700 K),
- run at the same temperature, to deliver the same spectral distribution,
- end effects of cooling by the filament supports negligible
- power emitted proportional to surface area of filament ($2\pi rL$)
- resistance of filament proportional to $L / (\pi r^2)$

In general for n times more power, area is n times bigger:

or

Also the resistance must drop, if the current is to be n times bigger:

or

So

and

It is interesting that there is only one solution to this problem, and that it explains why higher power lamps (car headlamps) take so long to cool down. The volume of the new filament (and so its thermal capacity) are bigger by a factor of 46.

Technician's note: The demonstration is more dramatic in a darkened lab, so that luminous power of the series of bulbs is more easily assessed.

The d.c. power supply must be continuously variable (or a rheostat included in the circuit) so that the effect of supply internal resistance can be compensated for, as larger currents are drawn by the more powerful lamps.

Alternative Approaches

A hazardous alternative. It is possible to arrange a suitable car headlamp and mains lamp in series, so that the same current flows through both, but the power dissipated is very different. This very clearly makes the point that the potential difference affects the power per unit current. If you do this you must follow these safety precautions:

- (a) use a transformer with a 1:1 ratio but with the secondary not earthed at all
- (b) all connections made with the power off
- (c) all leads to have shrouded plugs or all connections made with mains plugs.

2.2 optional Activity 140E: Experiment The filament lamp: The relationship between power and applied potential difference

Requirements

4mm leads

Stopwatch

Filament lamp 12 V, 24W

2 digital multimeters

Power supply, 0 – 12 V d.c.

Smoothing unit

Joulemeter (as an alternative for which instructions are provided)

Practical Advice

You may like to use smoothing units, if available. However purchase is not justified for this occasional use, and they are not listed in apparatus requirements for that reason. Similarly, the alternative method is only for those who already own joulemeters.

The experiment itself is very easy but students should be encouraged to check their readings. The handling of the data is important in this investigation. Either use the experiment for practice on log graphs and their use for empirical formulae or show the power of a spreadsheet for solving complex formulae. But do stress how it is easy to get a spreadsheet to fit a totally inappropriate relationship – for example a straight line fitted to an obvious curve.

Alternative method using a joulemeter: Many joulemeters come with dual ranges and a scaling of the reading. Most students will not have used a digital joulemeter and will need careful supervision. There is a class joulemeter on the market, but that requires 9–12 V and is only suitable if you choose the headlamp. Counting flashes on the meter is extremely tedious!

2.2 Activity 100E: Experiment Using a wide range of sensors

Requirements

Thermocouple (e.g. copper-constantan)
Semiconductor thermopile
Photovoltaic cell
Phototransistor
Crystal microphone
Other types of microphone
Rotary potentiometer mounted as angle sensor
Other commercially available active sensors
Detectors of potential difference, such as
Multimeter
Datalogger
Perhaps moving coil meters
Light beam galvanometer
PC-scope
Perhaps a gold leaf electroscope

Practical Advice

This experimental activity requires considerable and careful preparation. The nature of the sensors and detectors of potential difference provided, and of the tasks set, depends on the resources available.

Its purpose is two-fold:

1. to provide experience with a range of sensors, making students aware of the variety of ways in which effects can be sensed
2. to raise questions about measuring potential differences and about the properties of detectors, particularly their sensitivity, internal resistance and response time.

It is important to keep this early experimental work on sensors simple. Tasks need to be rather obvious, even trivial, so as to keep attention on questions about the p.d. obtainable from the sensor, its internal resistance, and the properties of the detectors.

Detectors should be married up with sensors so that where possible at least one detector will give a poor result. For example a thermocouple should be tried with too insensitive a voltmeter, and a high resistance sensor should be provided with a low resistance voltmeter. Some ingenuity may be needed to achieve this: for example providing a cathode ray oscilloscope with a resistance across its input to be used with a crystal microphone.

All this means that, starting from the ideas in this resource, the teacher will need to prepare local worksheets for the activity, reflecting the equipment available. Of course, once done, this is a permanent resource.

NOTE: we suggest not including sensors that depend on a change in resistance at this point, such as light dependent resistors, thermistors or strain gauges, which require a potential divider or bridge circuit to be used in order to produce a potential difference. They appear later, as part of teaching about potential dividers.

2.3 Activity 200E: Experiment Potential dividers

Requirements:

Resistors (suggested values 300 k Ω , 150 k Ω , 100 k Ω , 75 k Ω)

100 k Ω rotary potentiometer

5 V smoothed d.c. power supply

Clip component holders

Digital multimeters

4mm leads

LDR

Thermistor (47 k Ω)

Hairdryer

Filament lamp 12 V, 48 W

Practical Advice

It may be helpful to give a demonstration of a resistive sensor being used to turn some device on or off, as a way of giving point to the work. Alpha kit modules make this straightforward.

These experiments can be kept simple by using rather high resistances and high impedance digital voltmeters. They will not be a success using low impedance moving coil voltmeters.

In experiment 4 the resistors used are compatible with a 47 kW bead thermistor. If your stock thermistors have different values, then select the first resistor to be about 3 times the nominal resistance of the bead resistor at 25 °C. The second resistor should be a little lower in value.

Alternative Approaches

Potential division may be introduced within the context of control experiments and projects.

In experiment 4 you may prefer to utilise an electronics kit such as the alpha range. Students can still take measurements of resistance and p.d. across the components.

2.4 Activity 240E: Experiment Internal resistance of a source of emf

Requirements

2 digital multimeters

Potato

0.5 cm x 2 cm copper sheet, 0.5 cm x 2 cm zinc sheet

2 pairs crocodile clips

Resistance substitution box

5 x 4 mm leads

Practical Advice

This is designed as a simple introduction to the phenomenon, followed by a more detailed look. The advantage of using a potato is the path the current might take between the electrodes is transparent. The idea of resistance internal to the cell and energy dissipated there is easier to appreciate if it the cell is visible.

Alternative Approaches

You could make 'cells' with artificially high internal resistance by soldering a resistor in series with a standard dry cell.

Solar cells, cheaply available from surplus suppliers, make good sources with appreciable internal resistance. The internal resistance alters with incident illumination and thus some experimentation is needed, with a 48 W lamp, to get optimum conditions. Then you can use 50 mA fsd and 20 V fsd meters to get a good plot. A 16 W rheostat functions as a variable load. You are warned that solar cells are not uniform in performance and some fine-tuning may be necessary.

External References

Solar cells can be purchased cheaply from recycling mail order suppliers and then mounted on electrical ducting.

2.4 Activity 260E: Experiment Monitor rapid changes in intensity

Requirements

Light dependent resistor
Phototransistor
Clip component holder
Resistor 10 k Ω
Power supply, 5 V d.c.
PC-scope
4 mm leads
Stroboscope
TV remote control

Practical Advice

A suitable light dependent resistor (photoconductive sensor) is an ORP12 and a suitable phototransistor is SFH309.
Components could be mounted to avoid awkward problems with optical alignment. Any infrared controller will do.

Alternative Approaches

Photodiode can be used in place of phototransistor

External References

Data for sensors can be found from CD-ROMs or websites for large electronic retailers, e.g. RS Components CD-ROM, Maplins.

2.4 Activity 270E: Experiment Calibrating a position sensor

Requirements

Linear position sensor
Rotary potentiometer
Digital multimeter
Power supply, 5 V d.c.
Screw thread arrangement
Measurement amplifier
Power supply unit for measurement amplifier
Vernier calipers

Practical Advice

This activity is suitable for all pupils. The 22 kW potentiometer will give, if carefully used, a 1 V deflection for the full movement of the sensor; the number of cells used may need to be varied. The 100 kW potentiometer will, with care, give fsd on a grey UNILAB meter with no shunt. A suitable linear position sensor is (e.g. RS 317-780) 0–5 kW

Suitable rotary potentiometers are: 22 kW linear (RS 387-751) or 100 kW linear (RS 168-178)
The screw thread arrangement is mounted on a small piece of wood level with the position sensor.
The screw thread should be of as small a pitch as possible.

Alternative Approaches

A high impedance multimeter can be used to measure the change of resistance directly.

2.4 Activity 280E: Experiment Measuring rainfall

Requirements

Rotary variable resistor, 5 k Ω

Resistance substitution box

Power supply, 5 V d.c.

Digital multimeter

Beaker, 400 cm³

Materials to make lever arm and float

Practical Advice

This activity is suitable for all students, though especially for those weaker at setting up electronics.

If a system like that illustrated is used the beam will need to be a tight fit or be glued into position.

If the float is attached by a stiff wire the wire should be about 10 cm long and 2 mm diameter.

A suitable variable resistor is a Rotary variable resistor, 5 kW (e.g. RS173-625). Low friction models are to be preferred.

Alternative Approaches

A commercial movement sensor could be used to check the sensor. Use of Op-Amp circuit to perform simple mathematical conversion from angle to height.

2.4 Activity 290E: Experiment Comparing a photodiode and a phototransistor

Requirements

Mounted photodiode

Mounted phototransistor

Resistor 10 k Ω

Power supply, 5 V d.c.

Filament lamp, 12 V, 48W

Power supply 0 – 12 V d.c.

Metre rule

Digital multimeter

Practical Advice

The experiment is suitable for all students but a calculation of the energy per unit area is for the more able.

Components should be mounted to avoid varying alignment masking the variation with distance. A suitable photodiode is SFH229 and a suitable phototransistor is SFH309.

2.4 Activity 300E: Experiment Using temperature sensors

Requirements

Bead thermistor
Thermistor probe
Thermocouple
Clip component holder
Resistance substitution box
Measurement amplifier
Power supply, 5 V d.c.
Power supply unit for measurement amplifier
Digital multimeter
PC-scope
Beakers, 400 cm³
Electric kettle

Practical Advice

This activity is suitable for all pupils.

The bead thermistor will have to be mounted: it can be araldited into a narrow tube, but the bead must be isolated from the body of the mount to give a low thermal capacity. As with all team tasks the students should be actively encouraged to engage their ingenuity to come up with neat solutions.

Suitable components are:

bead thermistor (e.g. RS 151-136)
thermistor probe (e.g. RS 151-120)
thermocouple (e.g. RS 219-4646)

Alternative Approaches

A wide range of similar sensors is available.

External References

Data for sensors can be found from CD-ROMs or websites of large electronic retailers, e.g. RS Components CD-ROM, Maplins.

2.4 Activity 300E: Experiment Monitoring vibration

Requirements

Bimorph element mounted on hardboard square
Bimorph element mounted on cardboard square
Signal generator
Vibration generator
PC-scope

Practical Advice

Suitable for all students but the depth of the research will vary with ability.
The plates are hardboard (3.5 mm thick) and card (0.72 mm thick) about 8 cm square. On each is mounted a bimorph element (RS 285-784). It has been found that double-sided adhesive tape is adequate – a piece of polythene sheet over the top surface avoids stickiness.
The leads from the element are soldered to a small piece of veroboard which is also secured to the adhesive tape. More substantial leads run from the veroboard.

Alternative Approaches

Any material can be used for the plates provided that a number of resonances occur over the frequency range.

External References

Data for sensors can be found from CD-ROMs or websites of large electronic retailers, e.g. RS Components CD-ROM, Maplins.

2.4 Activity 320E: Experiment The oscillations of a hacksaw blade

Requirements

2 x strain gauge mounted on hacksaw blade
2 resistance substitution boxes
Digital multimeter
Power supply, 5 V d.c.
Power supply unit for measurement amplifier
Measurement amplifier
Wheatstone bridge board (with zeroing resistor)
PC-scope or datalogger
G clamp – 4”

Practical Advice

Description of how the Wheatstone bridge works is for the more able.

Technician's note:

Suitable examples of strain gauges are RS 308-102

- The strain gauges have to be stuck to a hacksaw blade (25 cm) and leads will be needed to attach to external circuits; a possible arrangement is illustrated.
- For the bridge it is easiest to have a pre-made board to allow components to be mounted; ideally, the potentiometer should be part of the 'board'.
- For the measurement amplifier, a differential amplifier with a gain of about 100 is suitable.

Alternative Approaches

Other amplifiers can be used. With better pupils, the idea of a coupling capacitor could be introduced.

2.4 Activity 330E: Experiment Monitoring air flow

Requirements

Mounted pressure gauge

Measurement amplifier

Digital multimeter

Power supply, 5 V d.c.

Power supply unit for measurement amplifier

Vacuum cleaner (cylinder, adapted to blow air through tube)

Variac transformer a.c. 0 – 240 V

2 retort stands, bosses and clamps

Practical Advice

Suitable for all students but the depth of research will vary with ability while the weakest will need guidance.

Technician's note:

- The pressure gauge can be soldered onto veroboard which allows leads to be connected easily and acts as a convenient mounting point
- A suitable pressure sensor is RS 286-658
- 5 cm (approx.) of plastic tubing were used to connect the gauge to a funnel – a 'sawn off' plastic syringe proved suitable
- Any cylindrical vacuum cleaner can be made to blow air from its exhaust through a pipe (a diameter of 2–3 cm).
- The measurement amplifier needs a gain of around 1000.

Alternative Approaches

Other pressure sensors are available (e.g. Maplin) but these may need different operating voltages. Other measurements might include a verification of Boyle's law (needs 286-670 gauge connected directly to a syringe) or pressure in a balloon if a suitable air flow is not available.

External References

Data for sensors can be found from CD-ROMs or websites of large electronic retailers, e.g. RS Components CD-ROM, Maplins.

2.5 Activity 340E: Experiment Sensor project briefing

Requirements

Student project so requirements are varied

Practical Advice

These projects are intended to be modest in scope, occupying up to two hours of class time and an equivalent amount of independent study. It will be essential to advise students carefully as to the level of task they should undertake. A modest task well done will be better than an ambitious failure.

Organisation of equipment and resources is crucial. Lists of sensors and apparatus which can be made available, given out before choices are made, help keep choices in line with what is practicable.

Because this is assessed coursework, considerable stress needs to be given to the importance of the written report. Marking the work is straightforward, using the criteria set out in section 4.2.1 of the specification.

External References

The CD-ROM catalogues of RS Components Ltd and Maplins Ltd offer a very valuable resource. Full performance data are given for many items, which can provide a basis for exercises in data handling or comprehension, or as starting material for a class discussion (e.g. comparing two sensors).

Advancing Physics Coursework Handbook, published by OCR gives further details about managing, marking and moderation of the task.