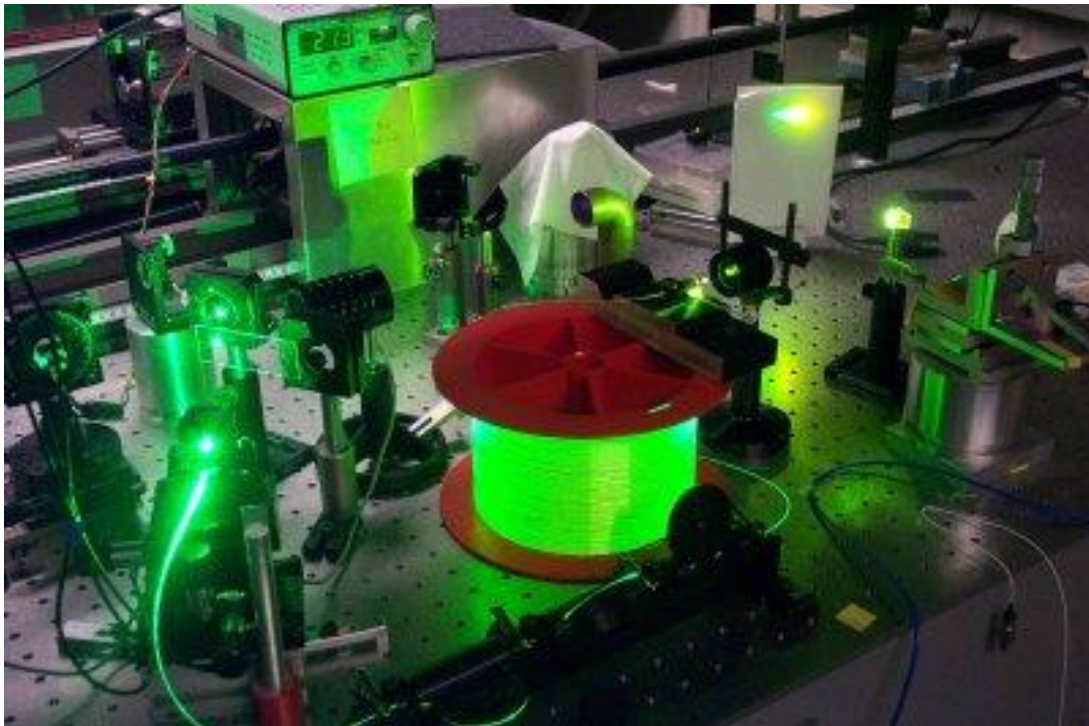# minilabs™

Experiments in Photonics

Section 3: Electronics & Photonics

An integrated electronic/photonic device. Photograph courtesy of Quantum Optics Group, Australian National University
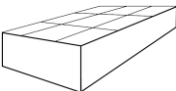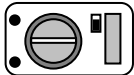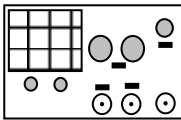
Electronics & Photonics
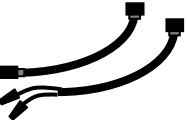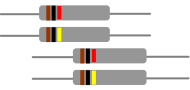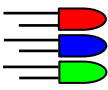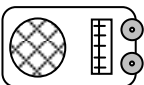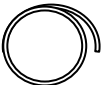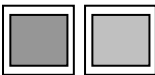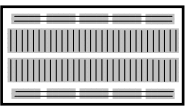
Aims

To use basic electronic components in the investigation of electro-optic devices such as thermistors, light dependent resistors, photodiodes, phototransistors, and light emitting diodes.
The study of transducers, energy transfers and amplification.
Investigate optical signal modulation and bandwidth limitations.

Equipment

	Optical bench		Optical Mounts		Meter
	Oscilloscope User supplied or optional		BNC/BNC BNC-clips		9 volt battery
	Resistors		Capacitors		Red, blue & green LEDs
	LDR		Transistor		Photo-transistor
	Radio		Optical fibre		Wire
	Microphone insert		ND filters		BNC T's
	Speaker (optional) or earphone		Mounted Electronic Bread Board		Variable Resistor

Minilab II comes with an earphone; but we have achieved excellent outcomes using a set of computer speakers.

3.1 Resistors

The resistor is a passive device used to limit current, reduce voltage or both. Resistors come in many different types and are often made of carbon. The carbon is mixed with an insulator in different proportions to vary the resistance.

low carbon level,
high resistance

high carbon level,
low resistance

Figure 3.1.1 Resistors of high and low resistance

The first circuit assembled uses a Light Emitting Diode LED supplied by a 9Volt battery with a current limiting resistor. The circuit should be built on the breadboard.
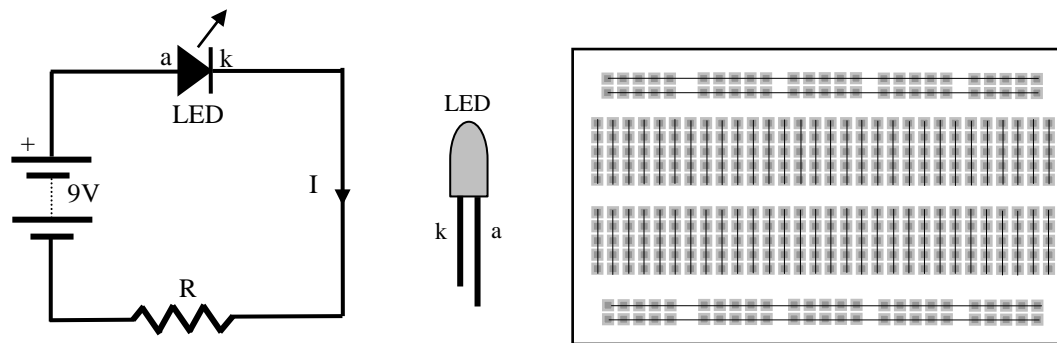
Figure 3.1.2 The LED circuit and breadboard connections

The breadboard has the component holes connected underneath the board. The four outer horizontal rows are connected lengthwise and the centre rows run vertically. See figure 3.1.2 for details.

Calculate the value of the resistor using the following equation:

$$R = \frac{(V_s - V_{led})}{I_{led}}$$

V_s = 9 volts, V_{led} = 2 volts and I_{led} = 10 mA

Choose the nearest value to the calculated value.

The 9V battery should be clipped in place and the circuit assembled as shown in figure 3.1.3, using a piece of connecting wire and the resistor.

Resistors can be identified from the colour code or more reliably measured with the meter set to the resistance range.

The LED has an anode (a) and a cathode (k) and must be connected the correct way round to allow current to flow. The LED should light.
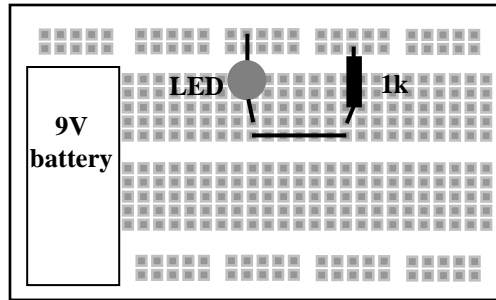
Figure 3.1.3 The LED circuit

Measure the voltage across the battery, resistor and LED.

Vbattery	Vresistor	Vled

Kirchhoff's Law states that in a series circuit the sum of all the (resistor) voltage drops equals the applied voltage.

Is Kirchhoff's Law upheld in this circuit?

This part of the experiment is about the properties of resistors. Set up the circuit to measure the current flowing through the resistor (and LED) Wrap a length of wire around the meter probes and push the ends in the breadboard to complete the circuit. Set the meter to the 20mA DC range.
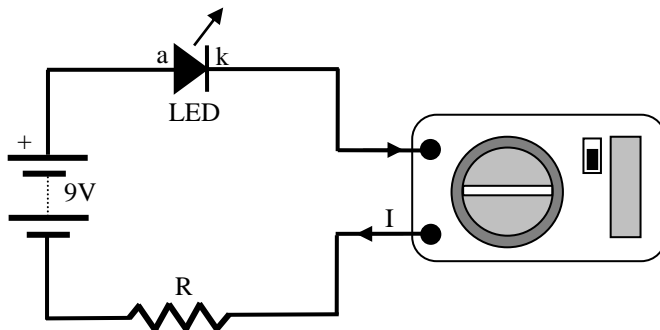
Figure 3.1.4 Measuring the current flowing through the circuit

The current is the same through every component in the circuit.

$V = I\,R$ where V is the voltage across the resistor and I is the current flowing through the circuit.

Complete the table and calculate the value of the resistor using Ohm's Law

Volts across R	Current ImA	Colour code R value	Measured R	Calculated R

Resistors are produced within tolerance levels, in this case ±10%. The meter typically has an accuracy of ±10%, so is the value of the resistor within the expected range?

Ohm's Law is of fundamental importance and can be verified using the following value resistors: 680 Ω, 1kΩ, 1.5kΩ, 2.2kΩ, 3.3kΩ, 4.7kΩ, 6.8kΩ and 10kΩ. In each case measure the current flowing in the circuit, refer to figure 3.1.4.

Resistance Ω	Current ImA	Calculated VR
680Ω		
1kΩ		
1.5kΩ		
2.2kΩ		
3.3kΩ		
4.7kΩ		
6.8kΩ		
10kΩ		

Tabulate the results and plot a graph of voltage against current. The LED provides a visual guide to the current flowing. Note a LED usually operates on 2 to3 volts and so a resistor is always needed with a 9V battery!

Does the graph confirm Ohm's Law?

Resistors can be used in series combinations. Connect the circuit shown in figure 3.1.5 with R_1 and R_2 in series.
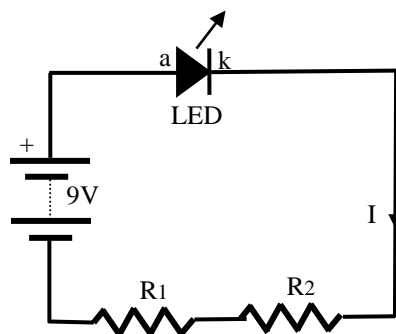
Figure 3.1.5 Resistors in series

Calculate the total resistance of the two resistors either using the colour codes or measuring each resistor with the meter and using the equation: $R_{total} = R_1 + R_2$

Measure the current flowing through the circuit. Measure the voltage across each resistor combination. Fill in the table and from the voltage and current calculate the total resistance of R1 and R2 in series.

Value of R_1 & R_2 to be used Ω	Calculated R_{total}	Current ImA	Voltage across R1 and R2	$R_{total} = V/I$
680 + 680				
680 + 1k				
680 + 1.5k				
680 + 2.2k				

Resistors can also be used in parallel combinations. Connect the circuit shown in figure 3.6 with R_1 and R_2 in parallel.
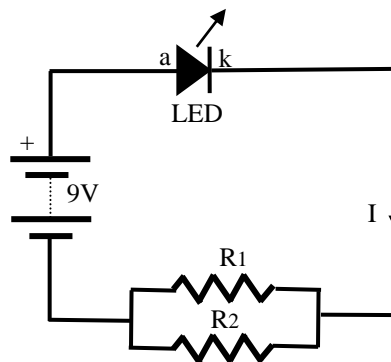
Figure 3.1.6 Resistors in parallel

Calculate the total resistance of the two resistors either using the colour codes or measuring each resistor with the meter and the equation:

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2}$$

Measure the current flowing through the circuit. Measure the voltage across each resistor combination. Fill in the table and from the voltage and current calculate the total resistance of R1 and R2 in parallel

Value of R_1 & R_2 to be used Ω	Calculated R_{total}	Current ImA	Voltage across R1 and R2	$R_{total} = V/I$
1k + 1k				
1k + 1.5k				
1k + 2.2k				
1k + 3.3k				

3.2 Capacitors

Capacitors are devices that store and release energy. They have many uses in circuits, for instance, storing charge to keep a computer clock running when the power goes off, making electronic filters, blocking dc or smoothing out the ripples in a dc power supply.
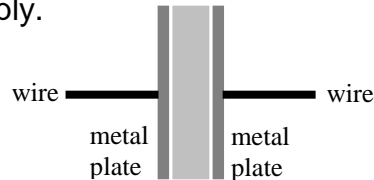
Figure 3.2.1 Capacitor construction

Set up the circuit using the 10μF capacitor and allow the capacitor to charge up. The capacitor is an electrolytic or polarised type. Connect the –ve side to the negative battery terminal and the +ve side to the positive terminal.
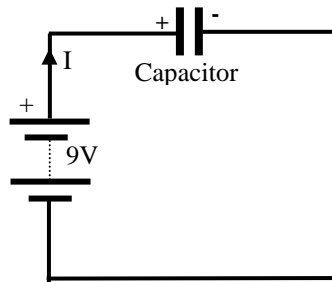
Figure 3.2.2 Charging the capacitor

Remove the battery and connect the meter in its place. Use the DC volts range. Be ready to record the time taken for the voltage to fall from the initial level to a relatively low level, fill in the first vacant column in the table.
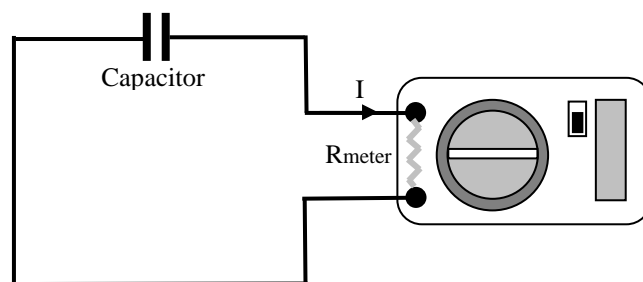
Figure 3.2.3 Discharging the capacitor

Voltage	Tsecs single capacitor	Tsecs series capacitors	Tsecs parallel capacitors
Initial voltage			
8V			
7V			
6V			
5V			
4V			
3V			
2V			
1V			
Final voltage			

The voltage across the capacitor decreases as the meter measures voltage using a resistor to sense the current. This is an example of how the act of measurement can change the state of an experiment!

Repeat the experiment with two 10µF capacitors in series as shown in figure 3.2.4. Remove the battery and connect the meter to measure the voltage drop, filling in the second column in the table.
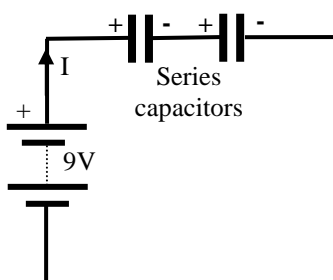
Figure 3.2.4 Series capacitors

Calculate the total capacitance of two capacitors in series by reading the values from the case and using the following equation:

$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2}$$

Next change the circuit so the capacitors are in parallel. Remove the battery and measure the voltage drop using the meter, completing the third column in the table.

Figure 3.2.5 Parallel capacitors

Calculate the total capacitance of two capacitors in parallel by reading the values from the case and using the following equation:

$$C_{total} = C_1 + C_2$$

Plot the discharge rates on a graph and explain how the discharge rates are related to the different combinations of capacitors.

From the graph it is possible to calculate the resistance of the meter. The measurements are based on the discharge equation:

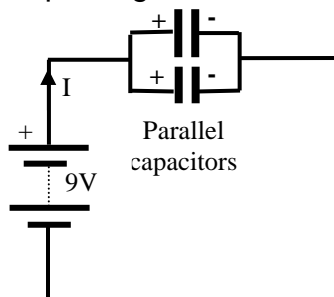$$V_c = V_o e^{\frac{1}{RC}}$$

where V_c = voltage across capacitor, V_o = original voltage, R = resistor value Ω and C = capacitor value Farads.

Capacitor discharge rate is characterised by the time constant, t = RC where:

$$V_c = V_o e^{-1} = 0.368 V_o$$

To calculate the value of the resistor in the meter Vo = original voltage.

Work out Vo x 0.368

Measure the time for the voltage to fall from Vo to this new level

As C is known calculate R using t = RC

Discuss the significance of the value of the meter resistance.

Construct the two circuits shown in figure 3.2.6 using 470uF capacitors. Connect the battery and charge the capacitors. Then disconnect the battery and observe what happens. Replace the 680Ω resistor with a 1.5kΩ resistor and repeat the exercise. Explain the behaviour of the LED in each case.
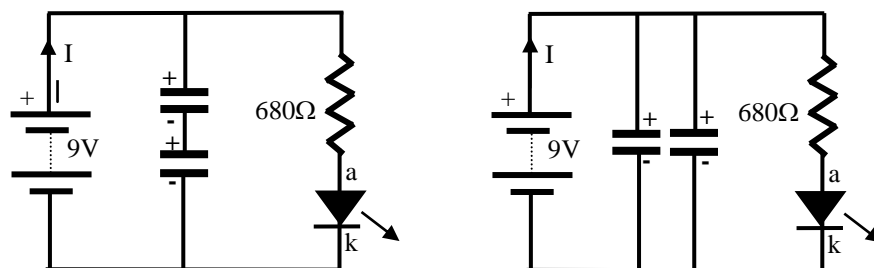

Figure 3.2.6a and 3.2.6b Charging circuit for a LED using series and parallel capacitors

Capacitors used in 240V equipment can store significant amounts of charge and must to be treated with considerable respect and shorted out to discharge the current.

3.2 Diodes and Light Emitting Diodes

An LED or light emitting diode works on the principle of band gap energies. A band gap is essentially the energy gap between the electron valence band and the conduction band. This gap is large for an insulator, small for a semiconductor and for a conductor these bands overlap, meaning that there are always electrons available in the conduction band.
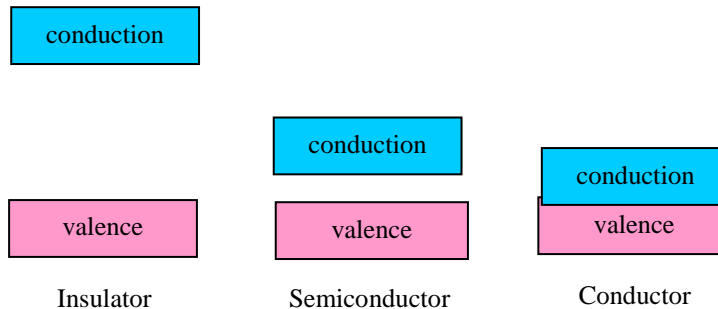
Figure 3.2.1 Relative positions of the valence and conduction bands in insulators, semiconductors and conductors

A diode is a device that allows current to flow only if it is in the right direction and is of high enough voltage. Diodes use a p-n junction. This is a term used for two pieces of semi-conducting material, one with positive holes (p) and another rich in electrons (n). When these materials are placed together, figure 3.2.2, the electrons and holes combine at the boundary to form a depletion zone that is electrically neutral and acts as an insulator.
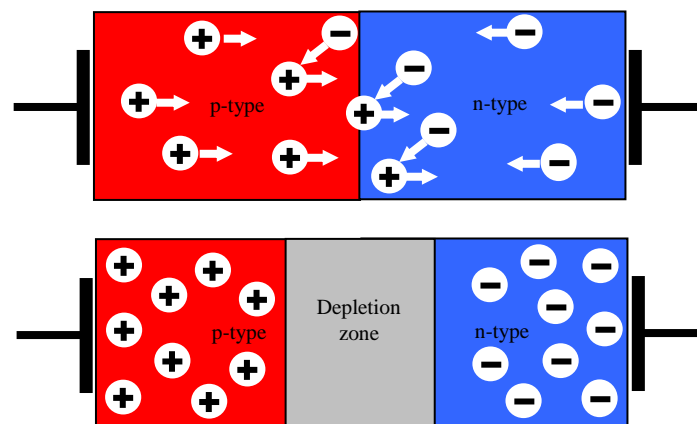
Figure 3.2.2 Holes and electrons in a p-n junction

If a high enough voltage is applied the electrons and holes migrate across the depletion zone. As the electrons drop into the holes they drop from the conduction band into the valence band and a photon of light is emitted.

light
emission
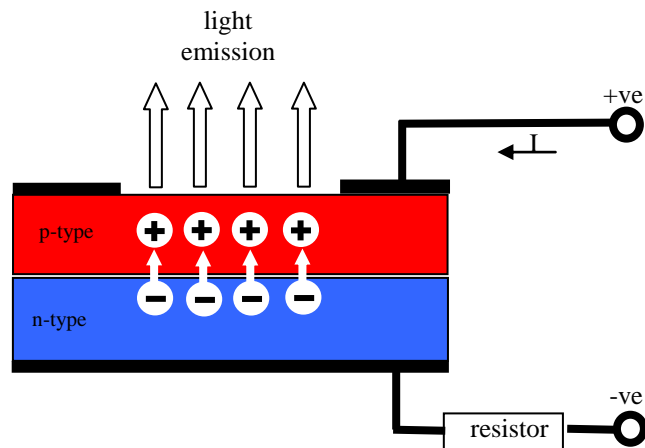
Figure 3.2.3 LED structure and circuit

LED's may be made from layers of Aluminium Gallium Arsenide (AlGaAs) in the form of a semiconductor chip encapsulated in epoxy resin. The composition of the LED can be altered to give different band gap energies. This controls the colour or frequency of emitted light. Small band gaps give red light and larger band gaps give green and blue.
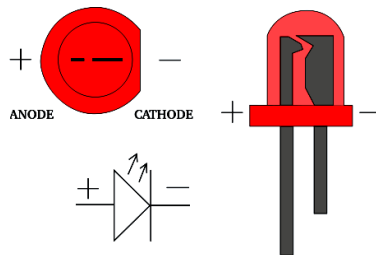
Figure 3.2.3 LED symbol, structure and polarity

A diode is a semiconductor device that allows current to move through it in one direction with far greater ease than in the other.
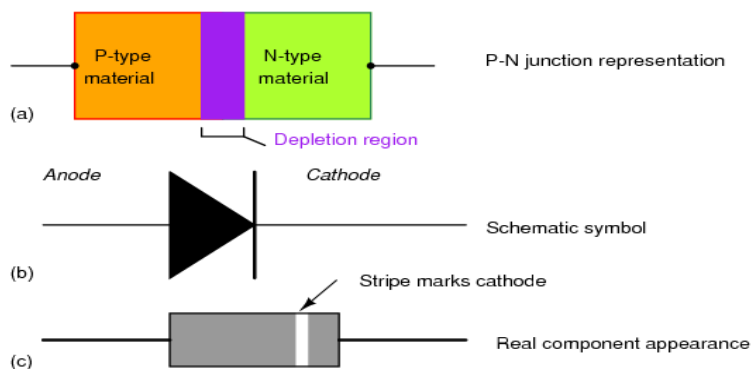
Figure 3.2.4 Representations of a diode

When placed in a simple battery-lamp circuit, the diode will either allow or prevent current through the lamp, depending on the polarity of the applied voltage.
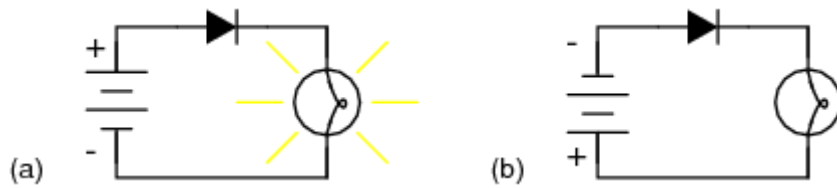
Figure 3.2.5 Diode polarity

When the polarity of the battery is such that electrons are allowed to flow through the diode, the diode is said to be forward-biased. When the battery is "backward" and the diode blocks current, the diode is said to be reverse-biased.

To make the diode conduct a small voltage of about 0.7 volts must be applied. This reduces the depletion region and allows the diode to conduct. If the diode is reverse biased the depletion region increases and current flow is blocked.
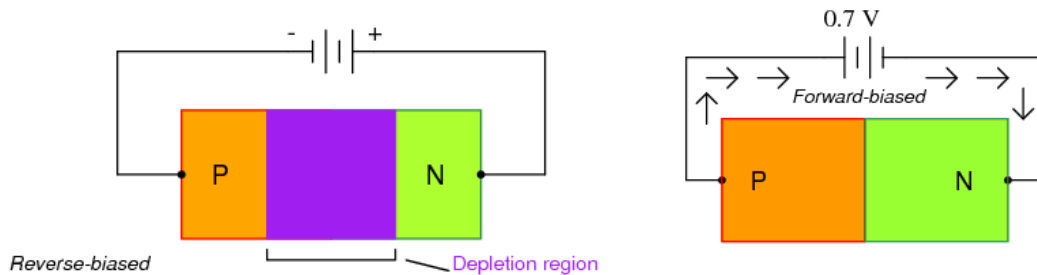
Figure 3.2.6 Reverse and forward biased diodes: Note depletion region

Set up the circuit below on the breadboard and measure the voltage across the diode with current flowing through the meter.
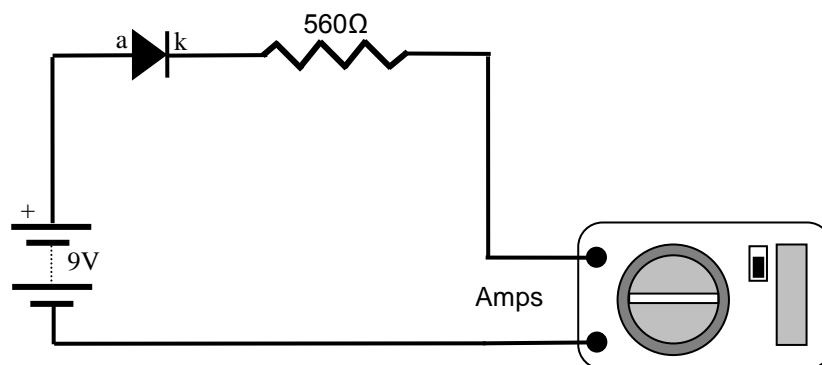
Figure 3.2.7 Diode circuit

Reverse the diode and record your observations. Replace the diode with a LED and repeat the measurements.

One of the most important applications of diodes is rectification: the conversion of alternating current/voltage (AC) to direct current/voltage (DC). A rectifier or high power diode can be used to convert an AC power source to a DC power source.

Connect a 50Hz sine wave to the upper circuit and observe the output from the diode across the 560Ω resistor. Use both channels of the oscilloscope to monitor the input and output wave forms.
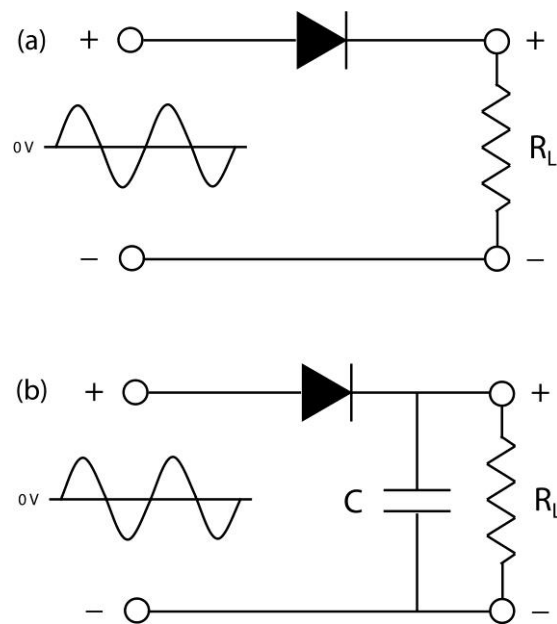
Figure 3.2.8: (a) Unfiltered half-wave rectifier. (b) Filtered half-wave rectifier.

Add in a capacitor to observe the output. Try values from 10µF to 47µF and observe the output. If the circuit is working correctly the output should be smooth and maintained at dc levels.

Which capacitor worked best?

List the similarities and differences between diodes and light emitting diodes

3.3 Light Dependent Resistors

The Light Dependent Resistor (LDR) is made using the semiconductor Cadmium Sulphide. The device is used in control circuits to turn lights on and in photographic exposure meters.

The resistance of the LDR decreases as the intensity of the light falling on it increases. Incident photons drive electrons from the valency band into the conduction band.
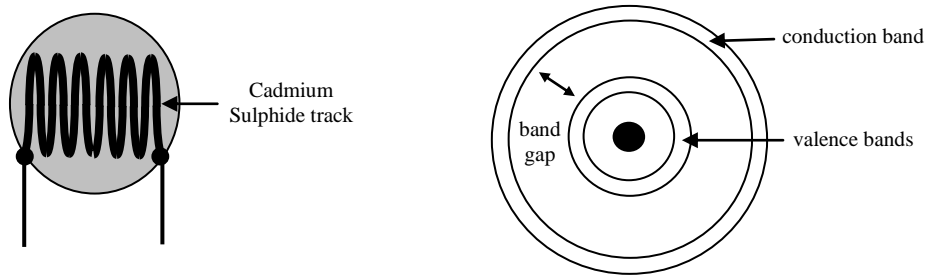
Figure 3.3.1 Structure of a Light Dependent Resistor, showing Cadmium Sulphide track and an atom to illustrate electrons in the valence and conduction bands

Measure the resistance of the LDR in the dark and in full light conditions, figure 3.3.2
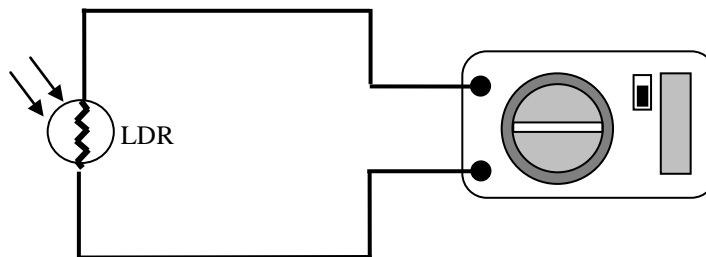
Figure 3.3.2 Measuring the resistance of the LDR

Resistance of LDR in the dark	
Resistance of LDR in bright light	

Build the circuit shown in figure 3.3.3 and observe the current flowing through the LDR at different light levels. Note the response of the LED. R1 =330Ω
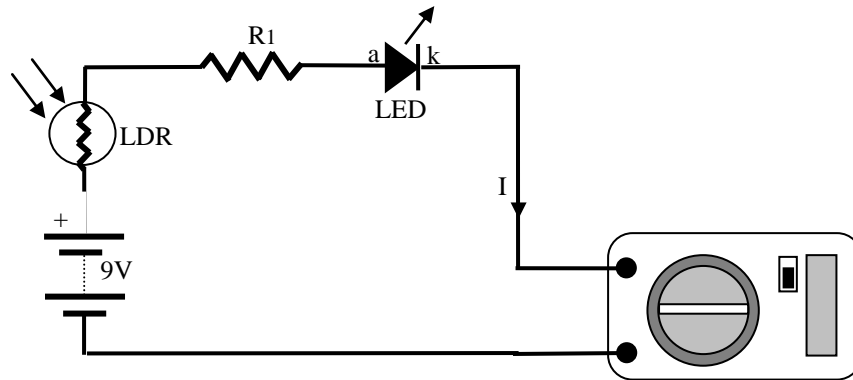
Figure 3.3.3 LDR and LED circuit.

Investigate the linearity of the response from the LDR by angling the LDR so it faces the white LED on the optical bench. Leave space, figure 16, to position the Neutral Density (ND) filters between the LED and the LDR. The breadboard is on a magnetic block and components can be fashioned to be at the same height as the other components.
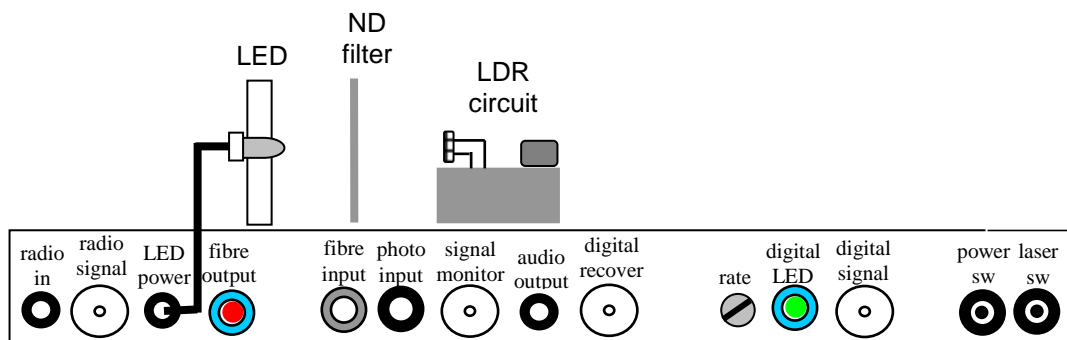
Figure 3.3.4 Measuring the response of the LDR to different light levels

The Optical Density of the Neutral Density filters can be calculated using:

$$OD = -\log_{10}\frac{I}{I_o}$$

I = transmitted light and I_o = Incident light.

Calculate the OD values for each filter and fill in the table.

The LDR should be connected as shown in figure 3.3.3. Measure and record the current flowing through the circuit with the different filters.

Calculate the resistance of the LDR at different light intensities, taking the resistance of R1 and the LED into account..

% Transmittance of filter	Calculated OD Value	Current mA	Calculated LDR resistance
100			
50			
25			
13			
7			

Plot a graph to show the relationship between the percentage of light transmitted and the resistance of the LDR. Consider whether it is necessary to take ambient light levels into account.

Repeat the measurements with a coloured LED.

% Transmittance of filter	Calculated OD Value	Current mA	Calculated LDR resistance
100			
50			
25			
13			
7			

Complete the table and provide an explanation for the results.

Extra Activity

Try using the curve fitting features in EXCEL to identify the type of response of the LDR to light.

3.4 Photodiodes and Phototransistors.

Photodiodes and phototransistors are used extensively to detect light pulses and convert them into digital electrical signals. In an optical fibre network these signals can be used directly by computers or converted into analog voice signals in a telephone.

Light meters or sensors on cameras use photodiodes.

One of the most common uses is in CD or DVD players to pick up the signal reflected from the digital encoding on the disc.
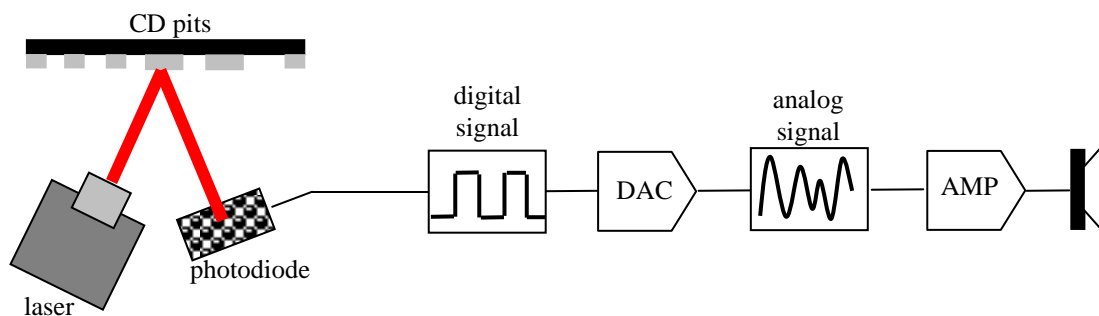
Figure 3.4.1.Optical signal recovery from a CD using a photodiode.

A photodiode is ideal for very fast signals but gives a much lower output signal. The phototransistor is used in the kit as it provides an amplified signal output and the signals studied tend to be relatively slow.
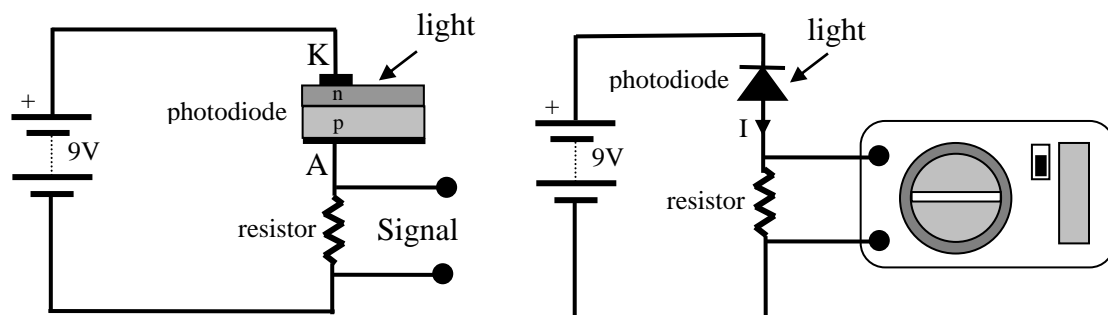
Figure 3.4.2 Structure of a photodiode, symbol and a negative bias operating circuit

All PN junctions are light sensitive. When a photon strikes the junction in a photodiode electrons are released and the formation of (positive) holes occurs.

If the two sides of the junction are connected a current flows. A photodiode is constructed from layers of p and n type silicon housed to allow light to strike the junction.

Figure 3.4.3 Phototransistor structure, symbol and operating circuit

In a phototransistor photons strike the base region of the transistor. This causes current to flow through the collector/emitter circuit and in effect amplification occurs. The base connection is not usually connected.

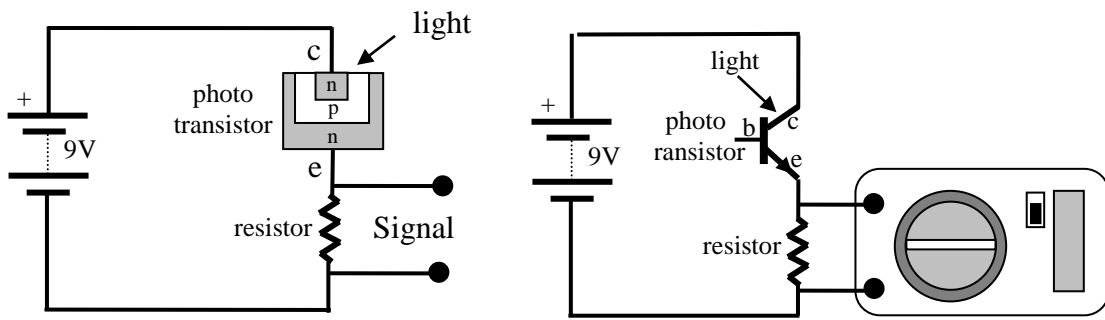Phototransistors, figure 3.4.4 come in a variety of forms and may resemble a LED with only two leads. Try the device both ways round.
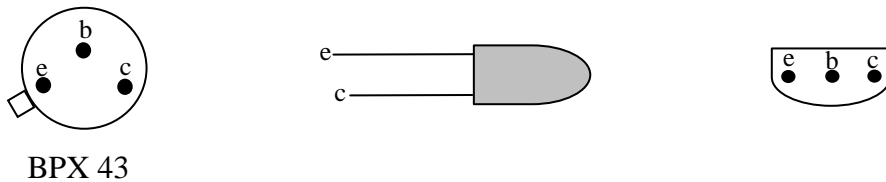
Figure 3.4.4 Phototransistor pin outs

Refer to figure 3.4.3 and build the circuit on the breadboard so the phototransistor faces the white LED on the optical table as shown in figure 3.4.5

The phototransistor is a BPX 43 and the pin out is shown in figure 3.4.4.

Start off with R1 at 1MΩ and record the voltage level on the meter.

If the photodiode is too close to the LED the device may saturate and not respond to the light level. Replace the resistor with the other values available in turn; taking care not to move the positions of the components. Complete the table.

resistor	1MΩ	560KΩ	270KΩ	100KΩ	10KΩ	1KΩ
volts						

Plot a graph to show the voltage output against the resistor value. It may be necessary to take background light levels into account.
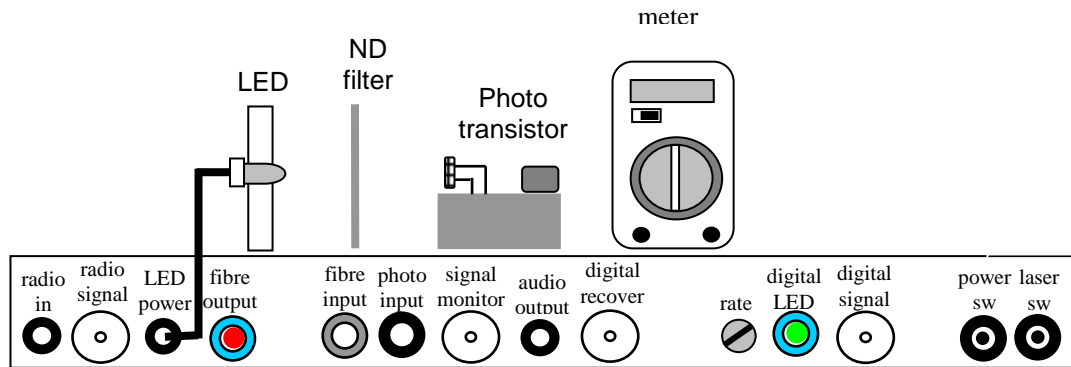
Figure 3.4.5 Phototransistor and LED on the optical bench

The response of the phototransistor to different light levels can be investigated by selecting a resistor that gives close to maximum output (but doesn't saturate). Place neutral density filters between the phototransistor and the LED.

% transmission	100	50	25	13	7
Voltage output					

To extend the number of samples use combinations of the filters Calculate the percentage transmission of each filter combination.

Plot a graph to display the results and explain the shape of the graph. Think of a suitable application for a detector of this type. It may be necessary to take background light levels into account.

The frequency response to pulses of light or changes in light levels is important in many applications. The phototransistor can be configured to give different response rates. Set up the optical bench and oscilloscope as shown in figure 3.4.6
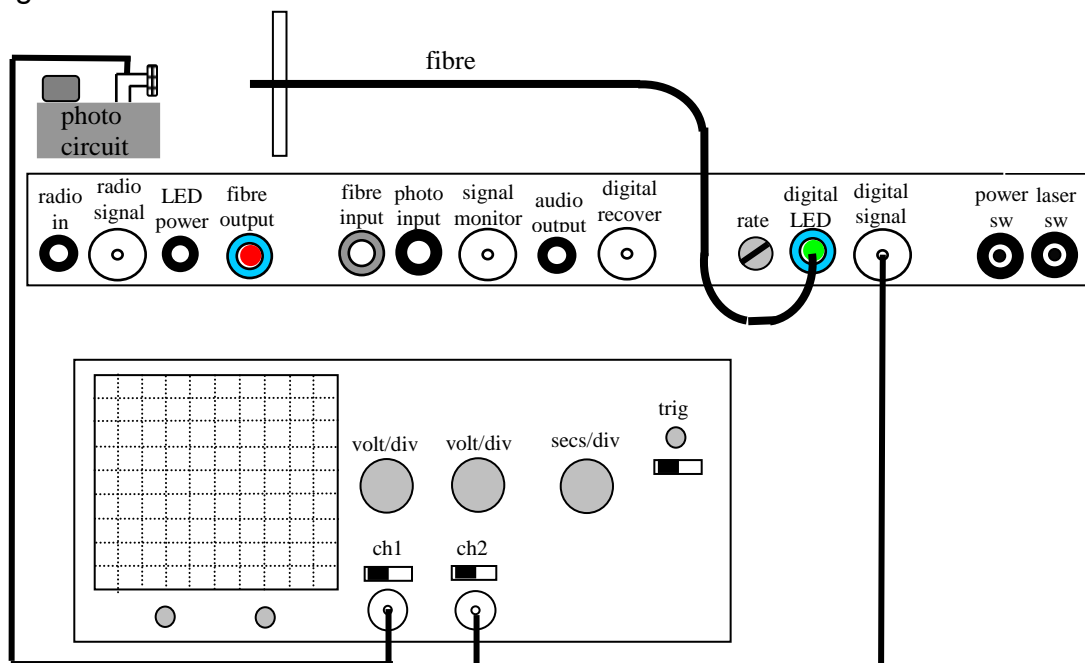
Figure 3.4.6 Pulse response rates.

The light output from a length of fibre inserted in the digital transmitter should cause a response on the oscilloscope screen. The oscilloscope should be attached to the output from the phototransistor.

Oscilloscope settings are Trigger None, Volts /Div 5V and Secs Div typically 20mS at the low flash rate and 100uS/div at the maximum rate.

Start with the 1MΩ resistor and note the response at the maximum and minimum flash rates. Sketch the waveforms seen on the oscilloscope.

1MΩ

560KΩ

270KΩ

100KΩ

10KΩ

1KΩ
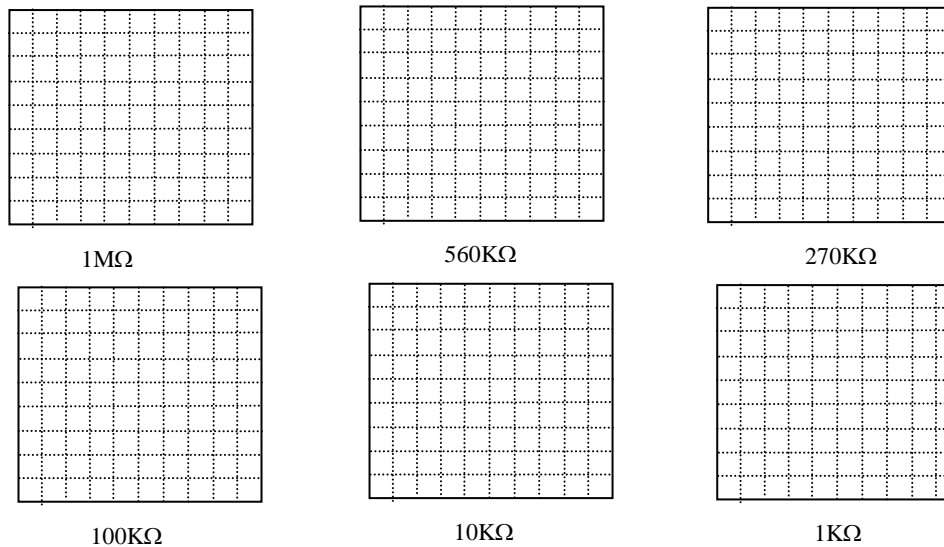
Replace the 1MΩ Resistor with the other values and repeat the exercise.
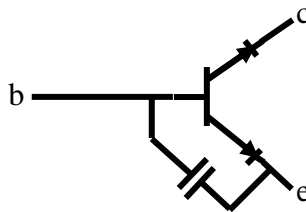
Figure 3.4.7 Electronic model of a phototransistor

Try to explain why the output pulses have changed at the higher flash rates. Reference to figure 3.4.7 may help.

As a further experiment switch between the DC-GND-AC switch on the oscilloscope and note what happens to the display.
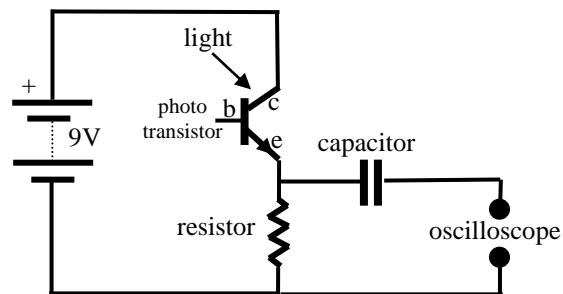
Figure 3.4.8 De-coupling capacitor used to remove DC

Switch back to DC and modify the phototransistor circuit with a 0.15uF capacitor between the output and oscilloscope lead as shown in figure 3.4.8

Explain the action of the capacitor. This is a very important property used later in the construction of transistor amplifiers.

3.5 Transistors

Transistors were invented in 1948 and have become the single most important invention in modern electronics. Before the transistor, expensive and inefficient valves were used to amplify signals.

Figure 3.5.1 Diagram and structure of a NPN transistor

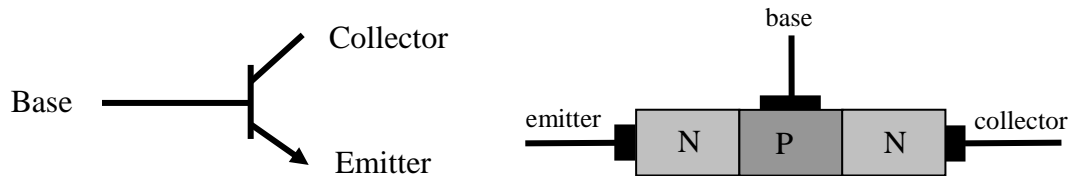A transistor has three arms, the Collector, Base and Emitter. The signal to be amplified is fed into the base and a larger voltage is applied across the collector (+ve) and emitter (-ve).

Current only flows from collector to emitter when there is a signal from the base. The base in effect controls how much current is allowed to flow from collector to emitter. In terms of water the base is like a valve that controls the flow of water from the collector to emitter outlets through the device.

The transistor in the kit is made from layers of silicon with small amounts of added atoms to make the material into a semiconductor. A semiconductor can act as an insulator or conductor depending on the conditions.

Silicon forms crystals by sharing electrons with other silicon atoms. The outer shell of silicon has four electrons rather than the eight needed to fill the shell.
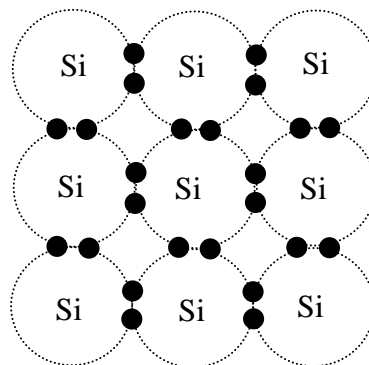
Figure 3.5.2 Electron sharing in the outer shells in a crystal of silicon

By adding small amounts of other atoms the silicon can become p or n type silicon, a process known as doping.

Boron atoms have three electrons in the outer shell. If boron atoms are added to silicon vacant electron holes are left and the material becomes positive or p-type.

Phosphorous atoms have five electrons in the outer shell and the extra electron makes the material negative or n-type silicon.

The transistor in figure 3.5.3 is an NPN type made from p and n type silicon. Note the P is phosphorous and B is boron.

emitter   base   collector

Figure 3.5.3 NPN transistor

For current to flow between the layers a voltage greater than 0.6 volts must be applied with forward bias. ie positive pole to the p-layer.
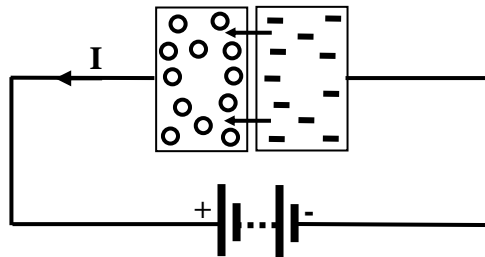
Figure 3.5.4 Forward bias applied to a p-n junction to give a current flow.
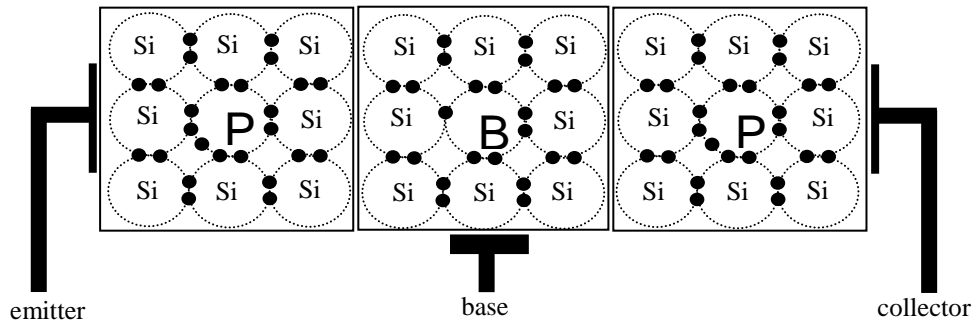
In an earlier exercise the change in resistance of a LDR in response to light was used directly to control the brightness of a LED. In low power applications this is sufficient. If higher powers are required the LDR cannot carry the current and would be destroyed.

The transistor is a device that can be switched on to carry larger amounts of power. The figures below show how the gain of a transistor can be calculated by measuring the base and collector currents and typical transistor curves as the base current is varied.

Figure 3.5.5 Transistor gain and performance as I_{BASE} is varied

Light Emitting Diodes (LEDs) are used in these circuits and it is necessary to wire in the devices with the correct polarity and to make sure the threshold voltage is reached so the device will illuminate. This threshold is usually around 1.7 Volts for red LEDs and 2.3 Volts for green LEDs.
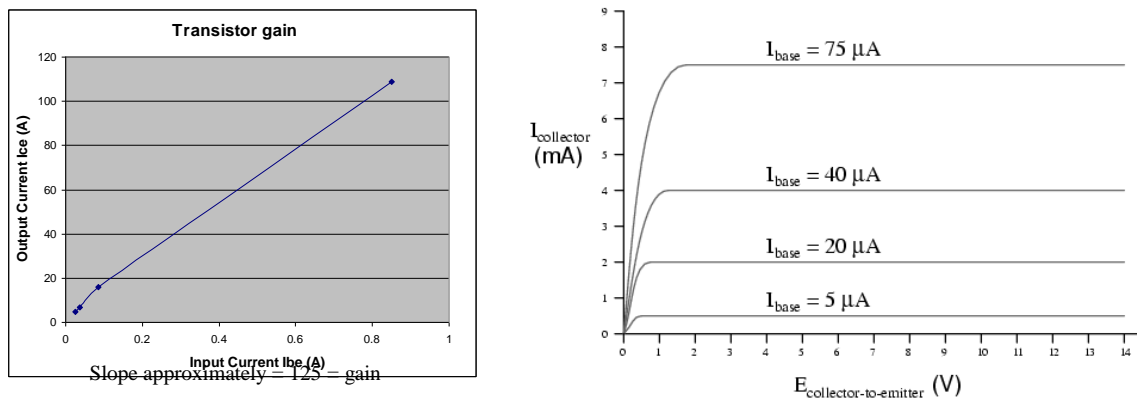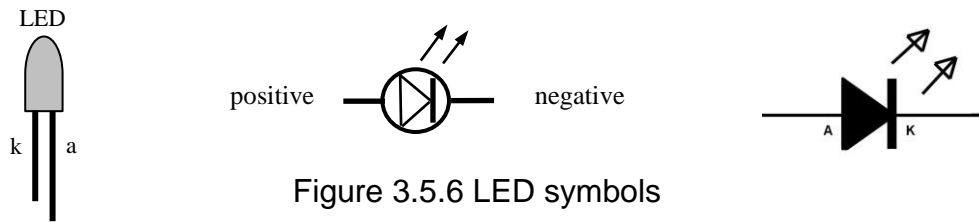

Figure 3.5.6 LED symbols

Transistor amplifier

The *base* current ('in') and *emitter* current ('out') of a transistor can be visualised by connecting LEDs to the transistor. Use resistors in the range of 2.2kΩ – 47kΩ to vary the input current to the base of the transistor. The circuit shown below can be constructed on the breadboard.
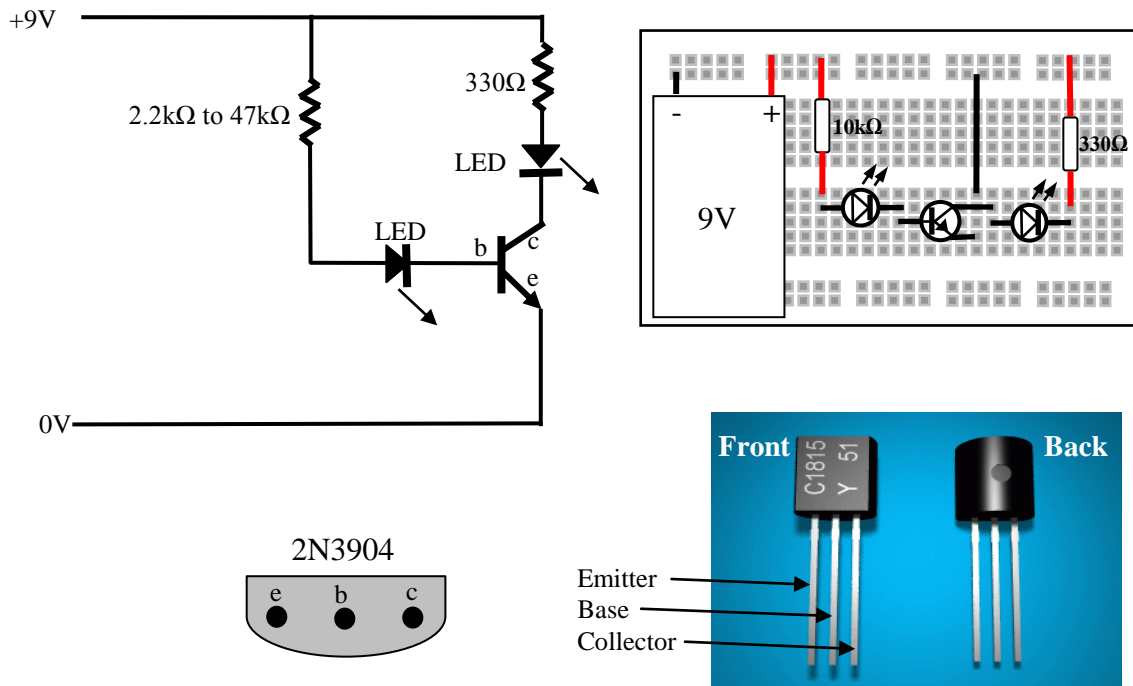
Figure 3.5.7 Circuit to demonstrate amplification

Which LED in the circuit is brighter and what happens to the LEDs when the value of the resistor is changed?

The gain of a transistor

The gain of a transistor can be calculated by comparing the input current (I_{BE}) and the output current (I_{CE}). One example of a circuit facilitating this is shown in figure 3.5.8 where the base LED has been replaced with an ammeter and another one is placed in series with the collector LED.

Figure 3.5.8 Measuring the gain of the transistor

Record the I_{BE} and I_{CE} for a range of resistors between 2.2kΩ and 47kΩ. Note that this resistor determines I_{BASE} Record the values as the voltage level is set at 0.5V intervals between 0 to 5V and plot the curves for several different resistor values.

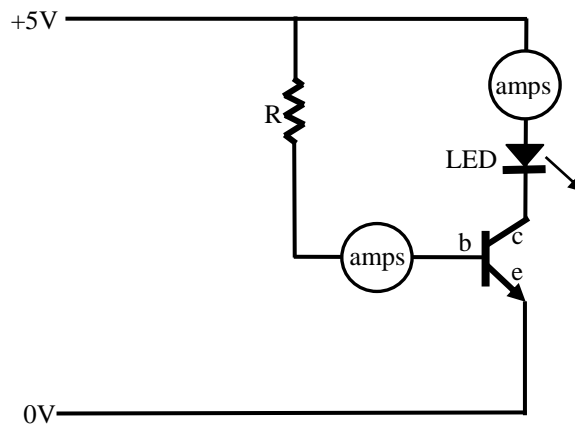Explain what the curves signify and identify an area on the curves where the transistor consistently amplifies an input signal. Use values for I_{BASE} and $I_{COLLECTOR}$ to plot a graph to determine the gain of the device.

Voltage Divider

The circuit in figure 3.5.9 contains a 10KΩ resistor in series with a 10KΩ variable resistor across the power supply. These two resistors form a voltage divider and allow precise voltage control.
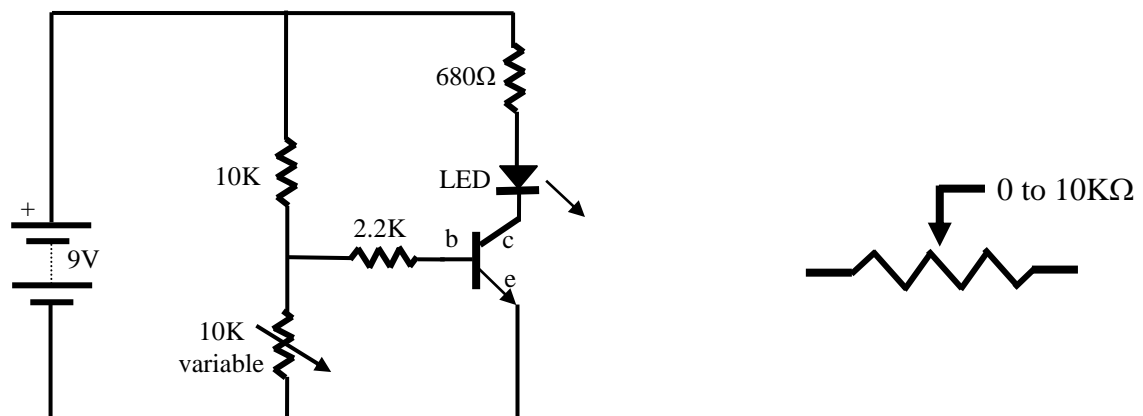
Figure 3.5.9 NPN transistor switch controlled with a voltage divider circuit

Build the circuit and note the variable resistor has a screw to adjust the resistance

Use the meter to monitor the voltage on the base of the transistor. Adjust the variable resistor to find the position where the LED first lights up.

What is the voltage level and is this a significant value?

Explain, using Ohm's Law how the voltage is varied at the junction between the two 10KΩ resistors.

Replace the 10KΩ resistor with the LDR. Adjust the variable resistor until the LED lights when the ambient light level is reduced.

Explain how the circuit operates and think of some potential uses for this type of on/off control.

3.6 Transistor amplifier

The circuit in figure 3.6.1 is one of the simplest voltage amplifier designs. It is capable of amplifying the low level signal from a microphone so it is suitable to drive the amplifier/speaker. Note this is only a voltage amplifier and to successfully complete this section the amplifier/speaker or an oscilloscope is needed to hear or see the amplified signal. It does not have sufficient power to drive earphones.

The connection between the circuit on the breadboard and the amplifier/speaker and the oscilloscope is most easily made using the signal monitor (BNC) and audio out (3.5mm stereo) connections on Minilab II
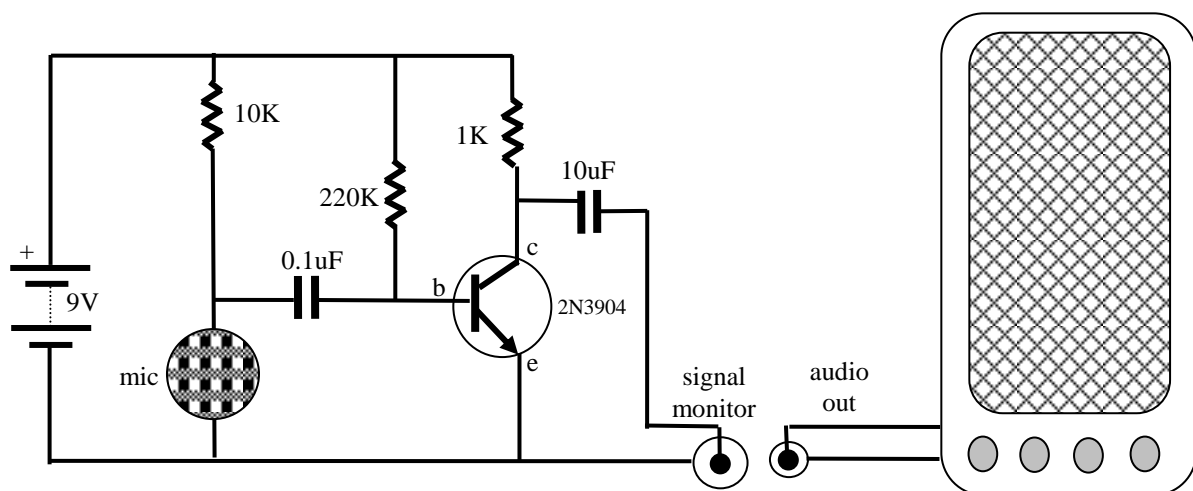

Figure 3.6.1 Transistor voltage amplifier

The bias resistor 220KΩ is selected to give an output voltage about half of the supply voltage. The transistor is always on and the signal "rides" on this steady voltage. This voltage is selected to allow the full signal range to be amplified.

These capacitors isolate the microphone and the next stage of amplification from the DC voltages present in the circuit. The microphone insert requires a voltage to operate, hence the 10KΩ resistor connected to the positive rail.

Build the circuit on the breadboard and connect the output to the speaker or oscilloscope.

If the circuit is built correctly the microphone output should be clearly heard. Figure 3.6.2 shows an analog waveform that has been amplified and is free of distortion or clipping.
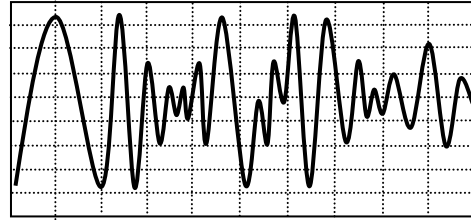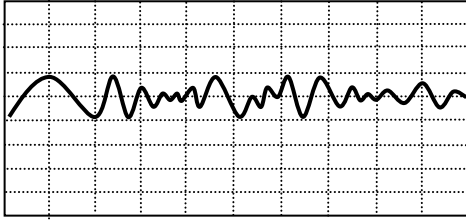
Figure 3.6.2 Microphone input and transistor voltage amplifier output

Typically the microphone gives an output of 3mV. This is amplified to about 100mV that is a suitable input for the amplifier/speaker.

Extra Activities

The oscilloscope can be used to measure the microphone input level (when you hum) and the transistor output level to estimate the gain. Observe the input and output waveforms to check for distortion.

Measure the DC voltage levels on the transistor base and collector.

Explain how the transistor amplifier operates.

3.7 Operational amplifiers

The use of transistors requires many additional components. The invention of the integrated circuit in 1958 by Jack Kilby opened up a whole new era for electronics.

Even the simplest Integrated circuits contain many transistors and the components needed to make a usable device.

One of the most used integrated circuits for signal amplification is the 741. The 741 integrated circuit is contained in an 8 pin package and needs only two resistors to produce an amplified signal.
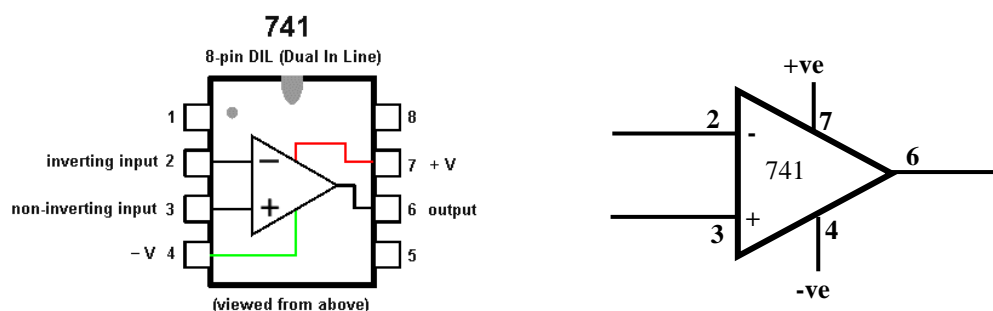
Figure 3.7.1 Operational amplifier in Dual in Line package and circuit symbol

The 741 has five pins that are used to build an amplifier. Normally the 741 operates using a **Plus - Ground - Minus** supply rather than a **Plus-Minus** supply like a battery, refer to figure 3.7.2
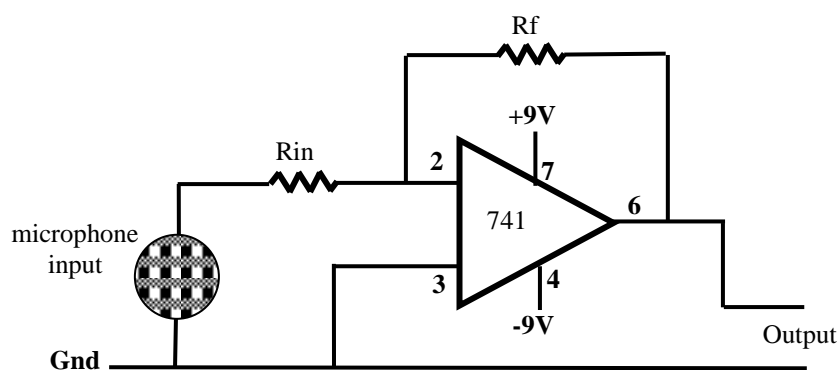

Figure 3.7.2 Basic amplifier configuration

The gain is set by the values of Rf and Rin. $Gain = \frac{R_f}{R_{in}}$

If Rin is10KΩ calculate the value of Rf to give a gain of 10

When the circuit is operational monitor the waveforms on the oscilloscope and try different values of Rf to change the gain. The amplifier is a voltage amplifier and does not have enough power to drive the earphones; but will drive the amplifier/speaker.

This is most easily connected using the audio out 3.5mm socket and signal monitor BNC on Minilab II front panel.

Build the circuit in figure 3.7.3. Note the microphone is an electret unit and needs a positive potential to operate; hence the 2.2K resistor. Also our circuit will use a voltage splitter and single battery to supply **Plus - Ground - Minus;** centre voltage will be 4.5 volts.

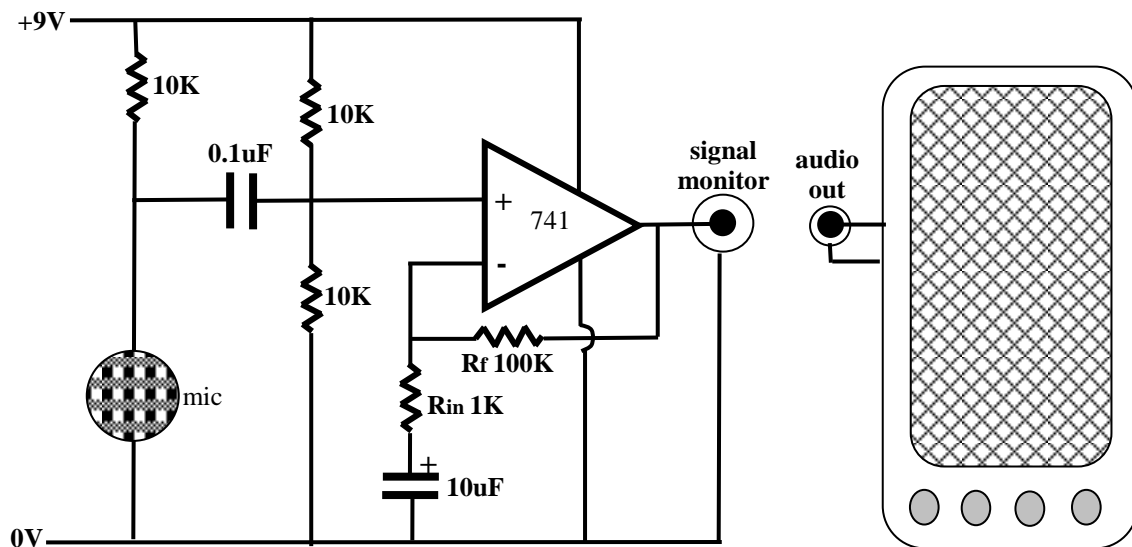Figure 3.7.3 741 amplifier

Identify the resistors that make up the voltage divider network. Measure the voltages.

Calculate the gain of the amplifier from the resistor values, R_f and R_{in}

In this case the gain is given by: $$Gain = \frac{R_f}{R_{in}} + 1$$

Try to think of an explanation (difficult) for the presence of the 10uF capacitor. Short it out and see what happens to the amplifier

Appendix A –Laser Classifications[1]

Class 1

Class 1 lasers are of very low power. They are intrinsically safe and cannot cause injury to the eye or any other part of the body. This may include lasers of higher powers enclosed to prevent access by personnel.

Class 2

Class 2 Class 2 lasers are low power devices that emit visible radiation (in the wavelength range 400nm to 700nm). These lasers are not intrinsically safe, but eye protection is normally afforded by aversion responses including blink reflex.

Class 3A

Class 3A lasers emit visible radiation and have an output power of up to 5mW. However the irradiance in the beam must not exceed 25 $W.m^{-2}$ Eye protection is advisable and the laser must be firmly fixed.

Class 3B (Restricted)

Class 3B (Restricted) operate at the same power levels as Class 3A but have a higher level of irradiance. These may be used in daylight conditions under the same safety controls as for Class 3A. When used in lesser illuminance the unprotected eyes may be damaged.

Class 3B

Class 3B lasers are medium power visible and/or invisible lasers. If the direct or reflected beam falls on the unprotected eye it can cause injury. Eye protection must be worn and correct operating procedures followed.

Class 4

Class 4 lasers are high-powered lasers. They are capable of producing hazardous diffuse reflections, may cause skin injuries, may constitute a fire hazard and must be treated with extreme caution. Eye protection is essential.

[1] AS/NZS 2211.1 Laser Safety Part 1: Equipment classification requirements and users guide

⚠ CAUTION

Do not stare at the laser beam
Beware of reflections
View the laser from above,
Use card or a screen to trace the path of the laser beam

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