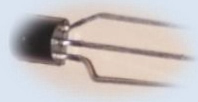
Basic Electronics Course – Part 2



Simple Projects using basic components – Including Transistors & Pots

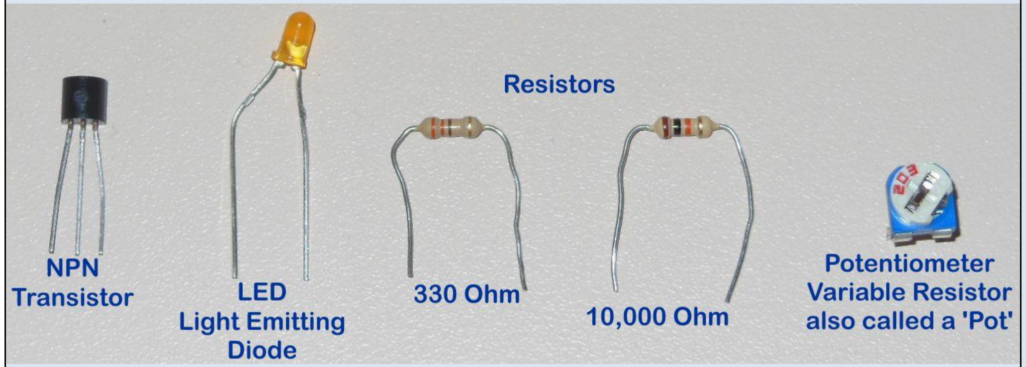


Image 7.
Components used in Part II

Abbreviations: ***+ ive means Positive + ive***
- ive means Negative - ive

Following are instructions to complete several electronic exercises

- **Demos 7,8, 9 & 10 follow Part I exercises & introduce Transistors, Pots & Capacitors**
- **Refer to Image and Description.** Image & text will assist you to duplicate what is expected – tick off each step as you build it !
- **More detailed notes are attached. Some steps** require more information so additional notes are provided at the end of this document. A "see ***Note xx***" alerts you to extra notes for this step or component. Find and read that 'note' if unsure about a step or a component
- **Know your components & remember the golden rule…** a circuit only works if it has an unbroken line of power running through it. If leads come loose or you miss joining one component to the next 'row', your Demo won't work
- **Look critically at your board and follow the line of power**

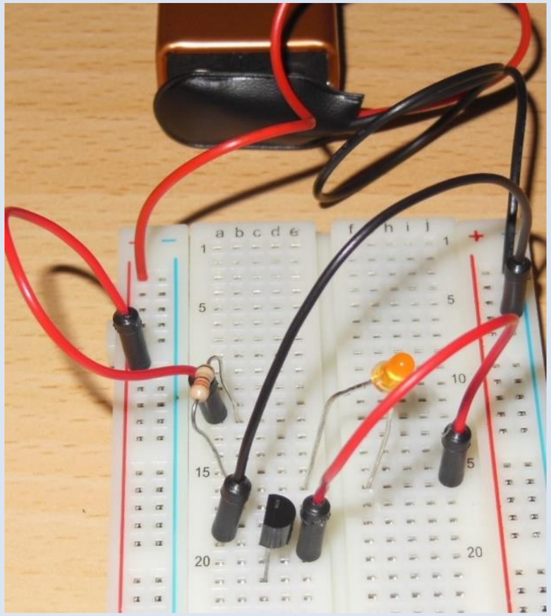


Image 8.

Demo 7: Use a simple Continuity Tester on Transistors [Set up Demo 6 [in Part I] on Breadboard to begin]

- **Using NPN Transistor from the parts kit** [***see 'note 4 Transistors*** If unsure of Transistor type or pin-outs Google the part number]
- **Imagine the transistor consists of two diodes connected back to back** - The NPN transistor has the anodes of the two diodes connected. *Suggestion; draw this circuit on paper to visualize what's happening*
- **The common anode leads are the transistor Base, the other leads are Emitter & Collector** - For this simple exercise, it doesn't matter which is Emitter or Collector.
- **Insert the transistor into the Breadboard** - with the flat side towards the +ive Rail and the legs occupying three Cross-Rows on the board. This give access to each transistor leg so power can be applied to each leg.
- **Test one leg first - Insert the +ive jumper lead** (the one from the LED) into a hole in the same row as the centre **Base** transistor leg.
- **Insert the –ive lead into** the same Cross-Row as one of the outer Transistor legs – **the LED will light**
- **Remove that same –ive lead & insert it in the cross-row of the other outer Transistor leg – the LED lights**
- Refer back to the hand-drawn circuit of the two diodes and note what is happening.
- **Try this - Swap the Positive and Negative leads over -** Insert the -ive jumper lead into where the +ive lead was connected to the Transistor Base [centre leg] & try the experiment again with the lead in one leg, then the other - the LED DOES NOT light.
- **What is demonstrated?** - A Transistor [equivalent to 2 diodes] conducts in one direction only & not the other. **See *'Note 4'* Transistors – for further tests and more information**

Demo 8: Turning a Transistor On & Off using a Potentiometer

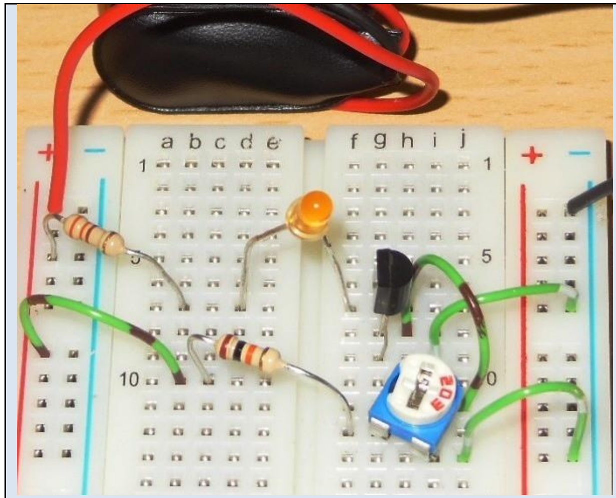


Image 9a

Use fine wire jumpers to allow more space on board

Spread out components for a better view & to ensure components are linked

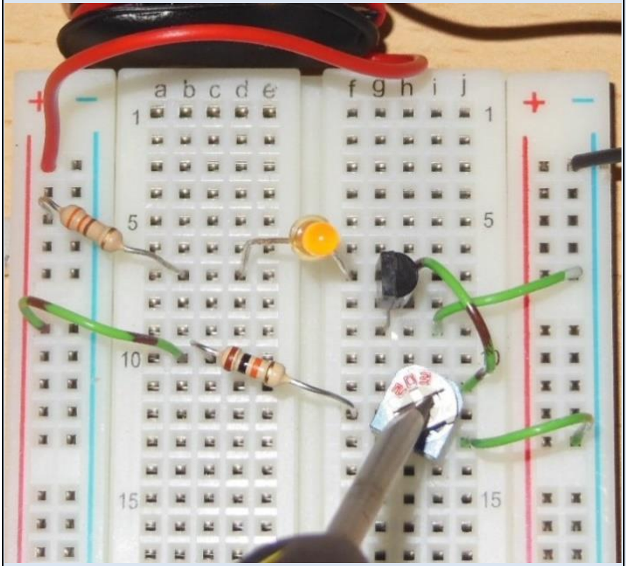


Image 9b

Screwdriver slowly turns 'slot' in the top of the Pot.

LED will light/brighten

Turning other direction LED will dim/go out

- **By varying the Base voltage [called the Bias] a** Transistor may be turned On and Off
- **Use a Potentiometer** [in the kit] to vary the voltage
- **A potentiometer** (also called a **Pot**) is a **Variable Resistor** - the 2 outer pins have a fixed value in Ohms [pot in kit is 20,000 Ohms] ***See "Note 5" Potentiometer***
- **Building this circuit - insert Transistor into Breadboard with legs in 3 Cross-Rows** (this ensures you can access each pin of the transistor separately on the breadboard)
- **See Image 9a. Transistor 'flat side' faces +ive rail**. Transistor **Emitter is the Left leg**, [lower row in photo] **Base is the Centre** row and Transistor's **Collector is the Right leg** [in the upper cross-row]
- **Add jumper lead 1** – one end in Emitter cross-row – other end into the –ive Blue rail
- **Insert LED:** +ive leg on one side of 'gap' in breadboard - -ive [short leg] into same cross-row as Transistor Collector leg [spanning the gap]
- **Insert 330 Ohm,** small (orange, orange, brown) **Resistor**. One end in same Cross-row as +ive LED leg. Other end directly into +ve supply rail.
- **The Emitter/Collector circuit is complete - Looking at the board:** +ive supply rail to Resistor to LED to Collector - through the Transistor to its Emitter, which is connected to the negative rail – **LED is NOT lit**.
- **Insert Potentiometer**: Place the Pot a few cross rows from the transistor
- **See Image 9a – pot is neither vertical nor horizontal on the board**. Each leg must be in a separate Cross-row so the pot must be rotated slightly. With each leg in its own row you can access each of the three legs on the breadboard.
- **The Pots Centre leg, or moving arm connection, is in the upper cross-row in Image 9a**
- **Add jumper lead 2** – one end in same cross-row as Pots right leg [lowest right corner in image]. Other end to the -ive supply rail.
- **Insert 10,000 Ohm,** large (brown, black, orange) **Resistor**. One end same cross-row as the Pot's outer Left leg. Other end spans gap and into any cross row
- **Add jumper lead** 3– one end same cross- row as 10K Ohm Resistor – Other end into +ive supply rail.
- **Add jumper lead 4** – one end same cross-row as **Pot's Centre leg**, the moving arm. Other end to same row as the **Transistor Base**.
- **The Controlling Circuit is complete** – **Looking at the board**: +ive supply rail to Resistor to Pot to other side of Pot to –ive rail
- Use small flat screwdriver in slot in Pot – turn fully counter clockwise position and connect the battery
- The LED should be OFF. Slowly turn the pot clockwise - the LED will turn ON
- **What has been demonstrated?** A Transistor can be turned ON and OFF using a Potentiometer and because the LED was also turned On and Off, the Transistor was being used as a switch.
- **Practice rotating the Pot extremely slowly** – there will be a fine point where Transistor & LED will turn On and Off with only a very slight movement of the screwdriver. ***See 'Note 6' Turning Transistors On & Off***

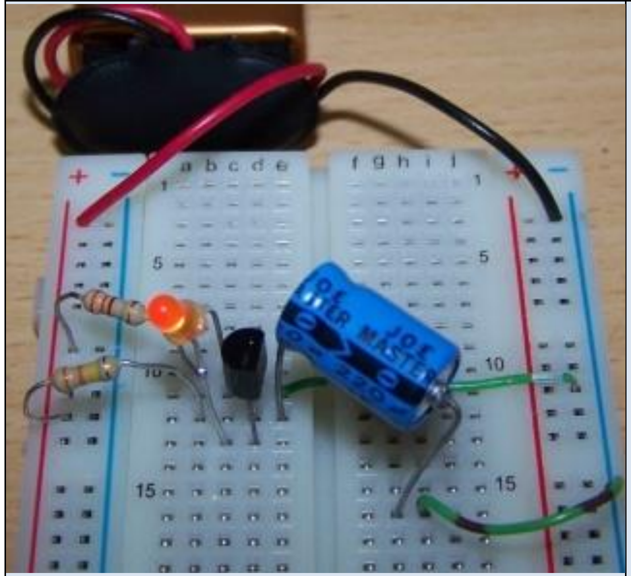


Image 10 – Transistor, LED, Capacitor & Resistors

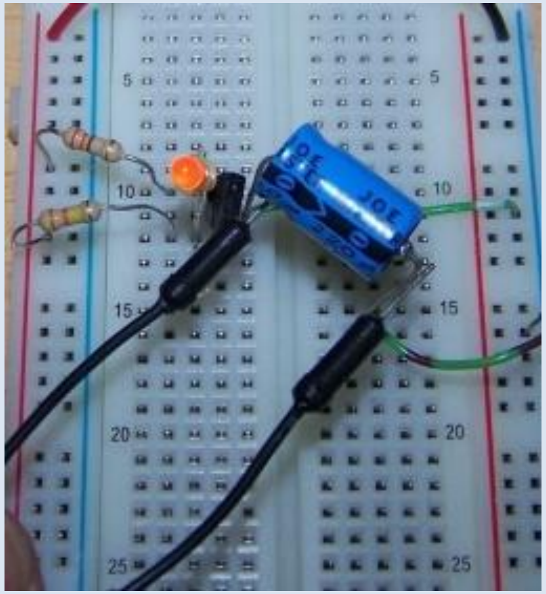


Image 11 – Short circuit the Capacitor – LED goes out

Introducing CAPACITORS

See *'Note 6' Capacitors* – for more information

Demo 9: Use a capacitor in a timing circuit *[begin with empty breadboard]*

- Insert NPN Transistor [BC548] into breadboard – flat side towards centre of board [***see 'note 4' - Transistors*** if unsure of Transistor's C,B,E pins/legs]
- Insert jumper lead from Transistor **Emitter** leg row to **-ive supply rail**
- Insert LED into board – Cathode [short leg] to same cross-row as Transistor **Collector** leg
- Other LED leg [+ive] to a **330 Ω** Resistor (orange, orange, brown)
- The other side of the resistor to the positive supply rail
- Insert **220uf Electrolytic capacitor +**ive leg to same cross-row as Transistor base;
- -ive leg into any other cross row – insert jumper lead from that row to -ive supply rail
- Insert **330K Ω** Resistor (orange, orange, yellow) from +ive supply rail to the Transistor Base row
- Circuit is complete
- Connect the battery leads to breadboard - **Watch the LED**
- *LED does not light immediately* - **count 6 seconds… LED slowly builds to full brightness**.
- **What is demonstrated?** It takes 6-8 seconds to charge a high value capacitor via a high **330K Ω** Resistor.

Demo 9 continues:

- **Short Circuit the Capacitor;**
  With battery connected, short circuit the capacitor - touch ends of a jumper lead to each leg of capacitor, at same time, to 'discharge' it – Note the LED goes out.
  Remove jumper lead & Note the timing cycle begins again [6 seconds later LED begins to glow again].

- **Check if Capacitor is 'holding a charge'**
  Disconnect the battery [remove one battery lead from breadboard], wait a few seconds and reconnect the battery [insert the battery lead again].
  LED lights almost instantly.
- **What is demonstrated?** – The capacitor held its charge & could quickly bring LED back to full brilliance without waiting for the full time period.
  Using the charging characteristics of a Capacitor we made a simple timing circuit.
  See 'Note 6 Capacitors - for more information.

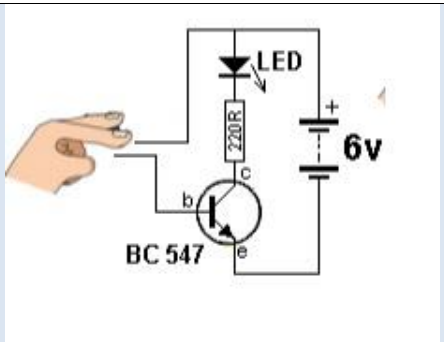


Image 12 – circuit diagram

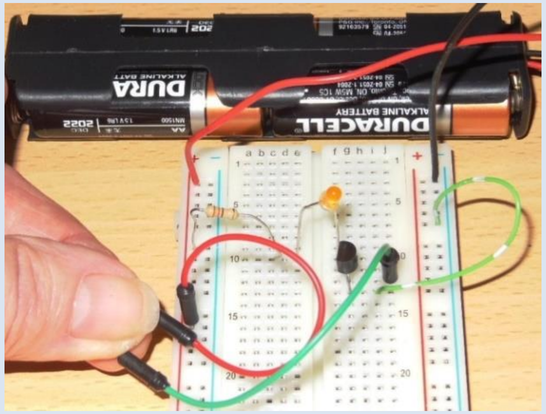


Image 13 – 6Volt circuit – on breadboard

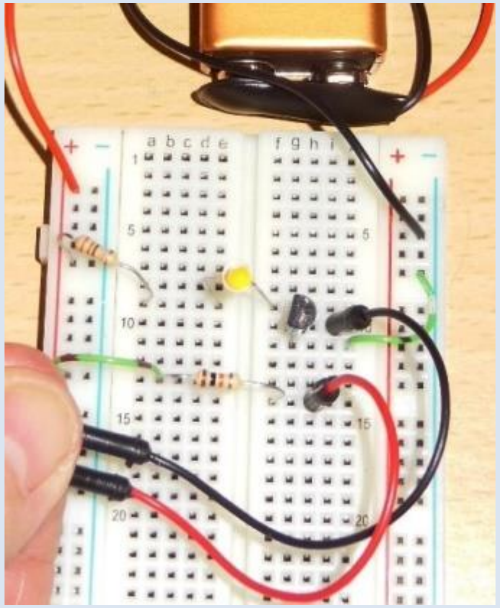


***Image 14** – modified circuit using 9V battery*

Demo 10. Follow a Circuit Diagram to <u>Build the Circuit on a Breadboard</u>

- *See Image 12* - a very basic circuit diagram [*specifying 6volt battery power*]
- *Image 13* is that circuit built on a Breadboard <u>using a 6volt battery pack</u>
- Trace the power loop around the Breadboard and compare to the power loop around the circuit diagram
- **What components are used?** – Circuit diagram shows; 6volt battery; LED; Resistor & Transistor – to make 'the lines' joining those components we use several jumper leads
- **Building the circuit with your parts kit – *<u>See Image 14</u>***
- **<u>Problem!</u>** Our kit has **9Volt battery – Voltage is too high – so how <u>can we build this circuit?</u>**
- **Solution: Place another Resistor [1000 Ohm] in the circuit** [as used in Demo 8] to protect Transistor
- **<u>Checking this Transistor – *See 'Note 4' Transistor - for BC548* – Emitter, Base</u>** <u>&</u> **<u>Collector configuration</u>**
- **Insert Transistor** 'flat side' towards +ive rail with legs in different cross-rows.
- *Image 12* - Transistor **Emitter leg in** lower cross-row, **Base is the Centre** row and **Collector leg** is in the upper cross-row
- **Add jumper lead 1**– one end in Emitter cross-row – other end directly into the –ive Blue rail
- **Insert LED: +ive leg on one side of 'gap' in breadboard & -ive [short leg] in same cross-row as Transistor Collector leg** [spanning the gap]
- **Insert 330 Ohm**, small (orange, orange, brown) **Resistor**. One end in same Cross-row as +ive LED leg. Other end directly into +ve supply rail.
- **Looking at the board:- +ive supply rail to Resistor to LED to Collector - through the Transistor to its Emitter, which is connected to the -ive rai**l – LED is NOT lit.
- **Insert 1,000 Ohm,** large (brown, black, orange) **Resistor**. Span gap, ends in any cross-rows
- **Add jumper lead 2** – one end same cross- row as 10K Ohm Resistor – Other end into +ive supply rail.
- **Add jumper lead 3** – one end in same cross-row as 10K Ohm Resistor [on other side of the board] – Other end Free [not connected to board]
- **Add jumper lead 4 -** one end in same row as the **Transistor Base – o**ther end Free [not connected to board]
- **Touch the two Free Jumper Leads together –** LED will light. Touching ends together completes power loop
- **Try this!** Take the Free jumper ends – one in each hand.
- Squeeze each wire end between thumb and finger – LED will light – squeeze harder & brightness increases! [wet fingers make it even brighter] *See Image 11b* – fingers are seen in lower right corner – current is flowing from breadboard, to one hand, through the body to other hand and back into the breadboard so the circuit is complete and the LED will light

What has been demonstrated? Using our fingers can light an LED just by the very small current going through your body. More precisely: With a very TINY current going via the BASE and COLLECTOR, a LARGE current then passes through the Collector and Emitter - This is the basis of how a Transistor actually can AMPLIFY a small signal, voltage or current

Notes on Components

Image 15
Different Transistors

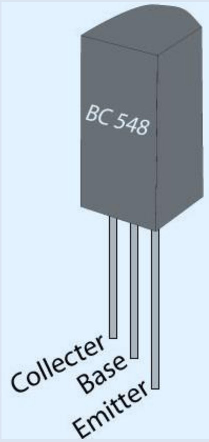
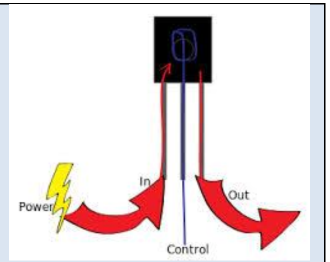


Image 16 – BC548 Transistor

4. ***Transistors***



Testing for Short Circuits OR Open Circuits in the Base/Emitter or Base/Collector junctions.

To make sure there are no short circuits between Collector and Base, take the two test leads [in Demo 7- remove from Breadboard & hold them onto the outer Emitter and Collector legs, first one way, then the other.
The LED should NOT light.

If the transistor fails these tests, it is faulty but more obscure things that can go wrong with transistors.

A PNP transistor is opposite in polarity to the NPN one. Imagine an PNP transistor as two diodes connected back to back with the two cathodes being common, so to test a PNP as in Demo 7, the polarity of the test leads would be reversed.

In Demo 7, it was not important to know which was the Emitter or Collector - it was simply a test of the Transistor. However to use a Transistor in a circuit it IS important to know which is which, so you know how to connect the legs into a circuit.

See Image 13. Not all Transistors are the same. Check Transistors carefully.

Transistors have numbers e.g. BC548 or N2222 or similar – Google an IMAGE search of the number on the transistor. You need to KNOW which pins are to be used for BASE, COLLECTOR and EMITTER

Image 13 shows the Emitter, Base & Collector configuration for Transistor BC548 in the Parts Kit – with ‘flat-side’ of Transistor facing you.

Use these configurations in the Demos 7, 8, 9 & 10 above

Image 17
Different Potentiometers

5. **Potentiometer** (also called a **pot**) is simply a **Variable Resistor** - the 2 outer pins being fixed at a value
The centre pin is the moving arm (sometimes called the “Wiper”).
When rotated fully one way makes the Resistor 20,000 Ohms on one of the outer pins and Zero Ohms on the other outer pin.
If the moving arm is rotated fully in the other direction - the pin that was 20,000 ohm value will be zero and the pin that was zero will now be 20,000 Ohms.
If the moving arm is at intermediate positions - intermediate value will result i.e. the total of the two add up to 20,000 ohms.
A common example of a pot is the volume control of a radio.
Also worth noting that pots come in a variety of different resistance values.

Notes on Components

Image 18
Various Capacitors – shapes/colours/values

Image 19 – Capacitor – Note 'Polarity' Arrow

6. ***Capacitors***

Capacitors can be used many ways; essentially they pass AC signals and block any DC voltage
Some Capacitors are Polarized See Image 19 - 1 leg goes to +ive side & the other leg to –ive side.
Note thick black line on side with –ive sign & arrow pointing to -ive leg [silver end is –ive; Insulated black end is +ive]
It takes time to charge the high value capacitor via the high 330K resistor.
Remembering capacitors only charge up to 0.6 volts to turn the transistor on (light the LED).
If the resistor has a higher value and/or the capacitor a higher value, the time period will be increased. Of course, if the resistor and/or capacitor values were lower, the time period will be decreased.

In the Short Circuiting Demo 9, the capacitor was discharged by touching the legs with metal.
It must slowly charge again to 0.6 volts.
Demo Disconnecting & reconnecting the battery - The LED lights almost instantly because the capacitor held its charge for a period of time. This is an important point to note!
What is demonstrated? – That by using the charging characteristics of a capacitor made a simple timing circuit.

7. **Turning Transistors On and Off**

Note there is a critical area between the transistor just starting to turn on, and being fully on

In the circuit in Demo 8, the Pots moving arm is connected to the transistor base. It's easy to imagine that by moving the pot control, the voltage on the transistor base is being varied from zero (with the moving arm fully counter clockwise) to around six volts positive with the pot at the other extreme.

The 1000 Ohm Resistor in the circuit serves to limit the maximum voltage [from the 9volt battery] allowed to flow through the circuit. This is to avoid the possibility of damaging the transistor or LED

When turning the slot in the Pot through that small area where LED lights – note the LED changes brilliance slowly - getting brighter as the pot is rotated one direction and dimmer as it is rotated in the other direction

If you were to measure the Base to Emitter voltage it would be happening at around 0.6 volts.

A little above this figure and the transistor is turned fully ON (max. brilliance of LED), a little below that figure.

We talk about varying the base voltage with the pot. Actually, the Transistor is a current amplifying device, rather than a voltage one.

So, from a more theoretical point of view, we are varying the Base current, which in turn, varies the Collector current at a greater rate (because of amplification).

However, where there is a current flowing, there has to be a voltage present, so really in this Transistor circuit, both current and voltage have to be considered.

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8. IMPORTANT "things" the Transistor Demos can illustrate

It shows The transistor as a switch and as an amplifying device.

We need to consider some voltage figures in order to understand these things. The accepted Bias or Base operating voltage of (in this case, a silicon) transistor is 0.6V.
We use this figure as the "centre" point for our calculations.
Assuming that the transistor works over a Base voltage range of 0.55V to 0.65V it means, in the case of the transistor switch application, as we turned the Pot from the minimum (or zero) voltage position, the transistor is "off" until we reach exactly 0.55V. And, above 0.65V it is turned on.

We must have a voltage present before we can have a current flow.

That Emitter/Base junction has a particular characteristic, in that it will NOT conduct until the voltage reaches 0.55V.
Because it is not conducting with the Base voltage between zero and just under 0.55V, no Base current will flow, and thus, no Collector/Emitter current will flow either. Thus the transistor is switched off over all that range.

At 0.65V the transistor switches fully on.
The maximum current is limited by the total resistance in that Collector circuit.
In our Demo, the 330 Ohm Resistor, the LED and some resistance internal in the Transistor.

We designed the Demo circuit to be 20mA, the maximum LED current.
So if we increase the Base voltage (and thus its current) above 0.65V, the maximum Collector/Emitter current is limited to that 20mA.
If we increase the base voltage (and thus its current) by a great amount, we exceed the maximum Base current specified for that particular Transistor.
The Base/Emitter junction will then overheat and burn out.
The 10,000 Ohm Resistor between the 9V rail and the pot is used to limit that base current to a safe value.

In summary: To use the transistor as a switch we turn it off with a Base voltage of less than 0.55V or turn it on with a base voltage of above 0.65V.
As these voltages are critical. We don't usually have a circuit at, or near, critical points. We would design our circuit with an "off" control voltage of say 0.3V and an "on" voltage of say 1V.

9. Critical Operating Area

The critical operating area is when the Base voltage is between that turn on and turn off point.
In Demo 8 the LED brightness varied as the Pot was slowly adjusted between the turn on and turn off point or voltage values of 0.55V & 0.65V on those points.

Slowly varying the voltage with the Pot from the 0.55V point to 0.65V point, then back to 0.55V point the LED went from dim to full brilliance & back to dim. This is a **full cycle** and may take 5 seconds, the time it takes us to gently vary the pot over that range.
To put this in AC [alternating current] terms – 1 cycle per 5 seconds - this illustrates how an AC voltage can be simply a changing DC voltage. ***"Important point 1"***.

That the small change of voltage (or current) at the Base is causing a far greater change of the Collector/Emitter voltage (or current).
In the Demo we vary the Base voltage just 0.1V (the difference between 0.55V & 0.65V) – a small change however it is causing the Collector voltage to change from almost 9Volts down to about 1volt [maybe even closer to zero].
We've changed 9volts down to 1volt a difference of 8Volts.
In other words - small change of 0.1V caused a change of 8V. The 'gain' (or increase) is 8 divided by 0.1 = 80 times.
The Transistor achieved something useful - Gain or amplification. ***"Important point 2"***.

This illustrates what is known as a DC amplifier.
Note, however, that the input voltage must be kept within a certain critical range.
The output voltage can only swing from close to zero to close to the supply voltage, so if the input voltage cannot drive the output voltage outside those limits.
If it tries to, there will be "non linearity" (a new term) meaning, in simple terms, the output does not faithfully follow the input.

Refer back to **"important point 1"** and quick introduction to AC - to take it further and explain a transistor as an AC amplifier.
We saw how 1 cycle (taking 5 seconds) an AC voltage was derived from slowly changing DC voltage. The frequency (1 cycles per 5 seconds) is extremely low considering mains voltage is 50 cycles per second, audio frequencies are around 1,000 cycles per second and radio frequencies range from a few hundred thousand to many million cycles per second.

Consider the transistor, biased at 0.6V with the collector voltage sitting at 4V (around the centre of its operating conditions). By varying the base voltage up 0.05V to 0.65V, the collector voltage drops to 1V (transistor turned on). By varying the base voltage down by 0.05V to 0.65V, the collector voltage rises to 9V (transistor off) – all DC related.

We super-impose a small AC voltage on that 0.6V bias voltage (coupled in via a capacitor so the DC bias point is not upset).
That input AC voltage is just sufficient to swing the base voltage over that 0.55 to 0.65V range and we can visualize the collector/emitter voltage, changing in sympathy, over its 9 to 1V range.
We saw this happening at a low frequency of 1 cycle per 5 seconds but we can visualize it happening at the higher frequencies - audio or radio frequencies.
So, that's how a transistor is operating, or inputting and outputting AC frequencies, or signals.

Note, from the above, as the base voltage rises, the collector voltage decreases (and vice versa). Thus the signals are "out of phase" (another new term) with each other. More on this later.
Also be aware it is conventional in all radio/electronic circuits, to measure voltages in respect to ground. In our particular case, the negative battery connection.