

Experiment 4: Diodes and Transistors

In-Lab Procedure and Report (30 points)

Before starting the procedure, record the table # you are working at in your Lab Report. Also record the EE Inventory # of any equipment that you use.

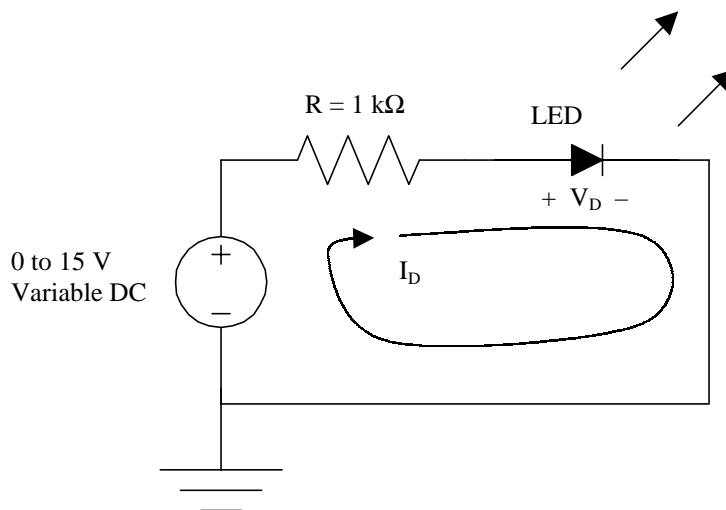
A major emphasis during this experiment will be for you to learn the proper method for taking data, recording the data in tables, and graphing the data. The experimental procedures have been kept fairly simple so that you can focus on these issues.

(1) Familiarize yourself with the equipment. You will use the following:

- Analog Trainer
- Digital Multimeter (DMM)
- Component Box
- The usual assortment of 16 banana-plug cables
- The wire tub.

If any of these are missing or non-functional, let your lab instructor know.

(2) Connect the LED circuit drawn below.



Note the following as you connect the circuit:

- Be sure to turn off the trainer and the component box power supplies before doing any circuit construction or modification.
- For the variable DC supply, use the +V source on the Analog Trainer.
- Measure the resistor using the DMM before connecting it in the circuit, and verify that it is in the correct range.
- Be sure to install the LED with the correct polarity. The anode (+) lead is slightly longer than the cathode (-) lead.

- (e) As you build your circuit, connect the current meter on the component box to measure the current I_D , and connect the DMM to measure the voltage V_D .
- (3) Make sure the DMM is set to measure voltage. Turn the +V control on the trainer to the MIN. position. Turn on the power to the trainer and the component box.
- (4) Verify that the circuit works before taking any data.
- (a) *Forward Bias Operation.* Slowly increase the supply voltage (turn the +V control toward MAX) and observe the LED and your meters. When the voltage V_D reaches approx. 1.7 V, the LED should turn on, and the current I_D should be less than 1 mA. When +V reaches the MAX position, the LED should be glowing brightly, the voltage V_D should be about 2 V, and the current should be in the range of 10 to 15 mA.
- (b) *Reverse Bias Operation.* Turn the supply voltage to MIN. Turn off the power to the trainer. Remove the LED and re-insert it into the circuit backwards. Turn the trainer power back on. Now increase the voltage. The diode should not conduct any current in the reverse direction, so it should not turn on. You should read $I_D = 0$ on the component box, while V_D varies from approx. 0 to -15 V on the DMM.

If your circuit does not work as described in steps 4 (a) and (b), you are not ready to take data. Examine your circuit for wiring errors and/or consult with your instructor until it works properly.

- (c) Turn off the power, return +V to MIN, and re-install the LED with its original polarity. Turn the power back on.
- (5) Carefully measure and record I_D versus V_D . The process of taking data carefully is not trivial, and will be addressed further by your lab instructor. However, some important points are discussed below. Read these, and then follow the example to take your data and plot the I-V curve for your LED.

Take the data using a three-pass process.

Pass 1: On the first pass, you sweep the variable supply voltage through its range and take a few data points - enough to get a general idea of the shape of the curve you are dealing with. Start by establishing the extreme ends of the data range, and then take some carefully chosen data in between. Then use this knowledge to decide how to take the data for Pass 2.

Pass 2: This is the "real" data pass. You have already decided how to take the data, and now you follow your established procedure, being sure to obtain maximum resolution and accuracy at each data point. While taking the data, record it in a table. After finishing Pass 2, you will plot the data.

Pass 3: Look over your data to see if it agrees with your expectations. Do you need to take more data points in a certain region? It is a good idea to go back and double-check some of the data you just recorded by re-taking a few readings. You should not replace the data you already took unless it is obviously erroneous.

An example that you should follow is provided on the next 3 pages.

Three-Pass Data Collection Example (LED Circuit):

Pass 1 (note that the data are recorded as taken - not necessarily in value order)

V+ knob position	V _D (V)	I _D (mA)	Observations
MIN	0	0	LED off
MAX	2.08	13.03	LED is bright, but the current is less than 20 mA, which is the max. allowed for the LED.
8 o'clock	1.770	0.2	LED just comes on
a little more CW	1.836	1.01	V _D did not increase much
"	1.872	2.05	current doubled, but V _D only slightly increased
"	1.942	5.08	current increasing smoothly, but V _D is not changing much at all.
nearly MAX	2.03	10.02	"

Pass 1 observations: The first two entries in the table serve to establish the extreme values. We can see the voltage ranges from approx. 0 to 2 V, and the current ranges from approx. 0 to 13 mA.

The remainder of the observations are taken in value order. We note that the current changes smoothly, while the voltage rises quickly at first, but then levels out.

Based on our observation, we decide it will be best to target regular increments of current, and measure the resulting voltage. One exception to this is that we should take another data point between V_D = 0 and V_D = 1.770 V.

Here is the chart we prepare for Pass 2:

I _D (mA)	0.		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
V _D (V)		1.													

The plan is to adjust the V+ knob to get close to each target value, and then record the actual current and voltage.

Pass 2: Here is the result of the Pass 2 data collection:

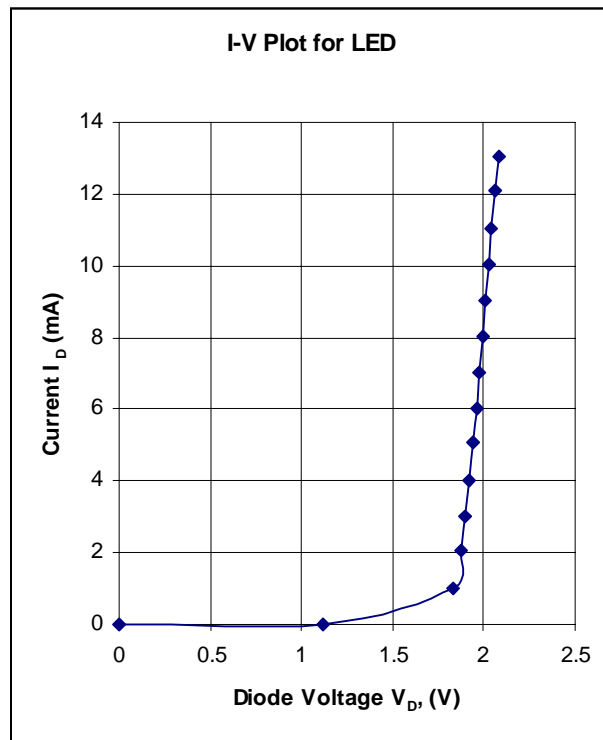
I_D (mA)	0.00	0.00	1.01	2.05	3.02	4.01	5.08
V_D (V)	0.00	1.120	1.830	1.872	1.898	1.920	1.942

6.00	7.02	8.01	9.02	10.02	11.06	12.08	13.03
1.960	1.979	1.997	2.01	2.03	2.04	2.06	2.08

Now we want to plot these data. Since we need to do it by hand in the lab, we should take some time to scale the data to our graph paper.

Suppose we use standard engineering paper with 7 x 10 major grid squares subdivided 5 times in each direction. One convenient choice is to let 2 major divisions = 1 V for the narrow direction (then each minor division = 0.1 V), and let each major division = 2 mA in the long direction of the paper (so each minor division = 2/5 = 0.4 mA).

Then we can plot the points with reasonable resolution and compare with our expected I-V curve, which is the Diode Equation given in the Prelab. Here is the result after connecting the data points with a smooth curve.:



Pass 3: Review the data and compare to expectations.

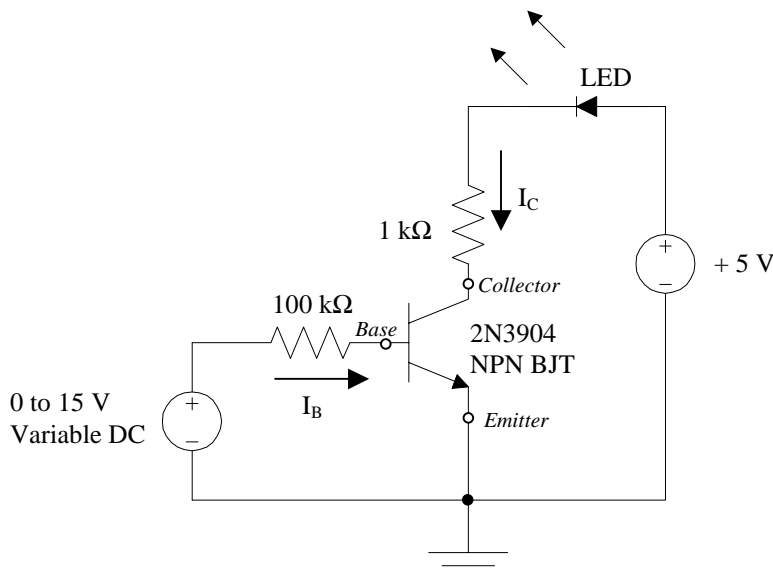
As expected from the diode equation, the curve does show an exponential increase in current starting shortly after 1 V. (The turn-on voltage of approx. 1 V for these LED's is higher than for silicon p-n junction diodes (approx. 0.5 V) because they are made of different material.)

Since the behavior agrees with our expectations, we can decide whether to take more data points to get a smoother curve. Clearly, the smoothness of the curve would benefit from some additional data around the turn-on point (between the 2nd and 4th data points). However, for your in-lab work, you do not need to add any more points.

END OF EXAMPLE

Continue with experimental procedure...

(6) Build the BJT circuit drawn below.



Construction notes:

- Measure and record the value of each resistor before you connect it in the circuit.
- Observe the polarity of the LED.
- Read the part number printed on the BJT – don't assume it's the right part just because it is in the bin.
- Use the photo below to identify the emitter, base, and collector of the BJT.
- While building the circuit, connect the DMM to measure base current I_B , and connect the Component Box ammeter to measure the collector current I_C .



Photo of the 3904 BJT in the TO-92 plastic package. With the flat side facing you, the leads are, from left to right, Emitter, Base, Collector.

The data sheet for the 2N3904 is available at: <http://www.fairchildsemi.com/ds/2N/2N3904.pdf>

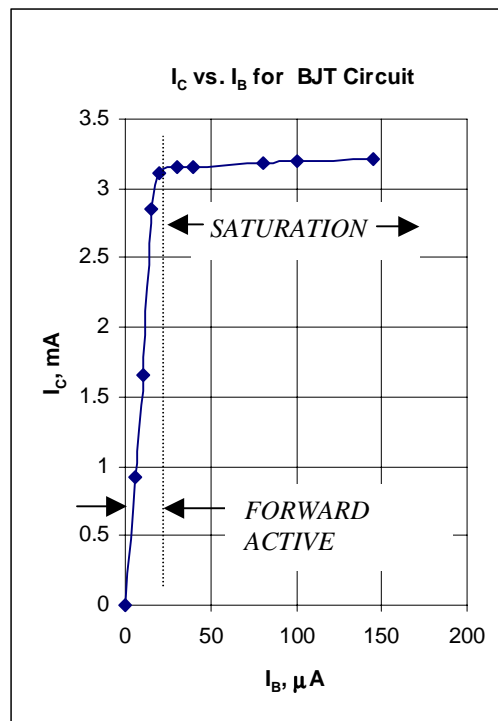
(7) Measure, Record, and Plot I_C vs. I_B

The base current is varied by varying the base supply voltage (V_+). Follow the three-pass procedure to record and plot I_C vs. I_B for your circuit.

The results of a typical experiment are recorded in the table below for your reference.

$I_B, \mu A$	0.0	5.3	10.4	15.1	20.0	30.9	40.3	80.7	100.7	145.3
I_C, mA	0.00	0.92	1.66	2.85	3.11	3.15	3.16	3.19	3.20	3.21

A plot of these data with the forward-active and saturation regions identified is shown below:



(8) Calculate the transistor β

In the pre-lab, we learned that the transistor is characterized by a current gain β in the forward active region. For example, from considering the plot shown above, we see that we can calculate β from the 2nd and 4th data points:

$$\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{(2.85 - 0.92) \text{ mA}}{(15.1 - 5.3) \mu\text{A}} = 197$$

Calculate the β for your transistor following this example.

(9) Answer the following questions:

- (a) In your own words, why is the transistor a useful device? (*Ans.: Because you can use a small control current to....*)

- (b) Suppose you wanted to control a really large current (say 10 Amps) using only a few mA. If you had as many transistors as you needed, can you suggest a way to do this? (*Hint: What if the working current from one transistor is used as the control current for the next one, etc....*)

(10) Cleanup

- (a) Turn off the power to the analog trainer and the component box
- (b) Turn off the DMM
- (c) Disassemble your circuit and place all wires back in the wire tub.
- (d) Replace the BJT and LED in the proper bins
- (e) Carefully replace your resistors in their bins. Use the color code to make sure you replace them correctly.
- (f) Clean up your workstation and discard any trash.

Review and Report Completion

Finish writing your lab report, following the outline given in the Course Information. Submit your lab report to your instructor before leaving the lab.