DIODE CHARACTERISTICS & BOLTZMANN CONSTANT DCBC-01

OBJECT

To determine the forward and reverse characteristics of semiconductor diodes like

(a) Germanium Diode.

(b) Silicon Diode,

(c) Zener Diode (3.9V)

(d) Light Emitting Diode

and to calculate the Boltzmann Constant

PACKING LIST

1. Semiconducting Diodes Characteristics & Boltzmann Constant, Model DCBC-01 : One

THEORY

The diode current equation expressing the relationship between the current flowing through the diode as a function of the voltage applied across it is given by

$$I = I_0\left(e^{\frac{qV}{\eta KT}} - 1\right) \qquad (1)$$

where I is the current flowing through the diode, I_0 is the dark saturation current, q is the charge on the electron, V is the voltage across the diode, η is the ideality factor, k= 1.38×10^{-23} JK^{-1} is the Boltzmann constant and T is the absolute temperature in Kelvin.

The ideality factor η indicates the nearness with which the diode under consideration behaves with respect to the ideal diode for which η is equal to 1. Its value increases from one as the difference between the behavior of the ideal diode and the diode under consideration increases. In diodes it varies considerably, while in transistors and IC's, η is close to 1.

1. Diode Characteristics

The typical characteristics of a semiconductor diode is shown in Fig. 1.

In the case of germanium and silicon diodes, and light emitting diode the parameters of interest are cut-in voltage V_c, dynamic resistance r_d, and the reverse saturation current I_0. However, in a number of devices the reverse saturation current may be too small to be measured. Zener diodes on the other hand are operated in the reverse mode and the parameters of interest include the zener voltage V_Z, and the zener resistance r_Z. All the characteristics mentioned above may be obtained with the experimental unit which consists of

(a) A variable voltage supply in the range 0-5V with current limiting at 60 mA (approx.).

(b) A 3½ digit voltmeter with a basic sensitivity of 200 mV which is used to measure all the voltages and currents. The current however is measured in two scales, viz. 200 μA and 20 mA full scale.

The unit uses an operational amplifier circuit so that the current and voltages are measured in almost idealized conditions, i.e. the input resistances of voltmeter and current meter are 100 KΩ and less than a mΩ respectively. This ensures non-interference between these measurements, which is otherwise very common.

Also, to get a better feel of the devices, a specially designed digital circuit has been provided which displays the forward/reverse characteristics of the devices on a CRO. A pair of calibrated axes (5V and 50mA) are also displayed.

Note: Although the reverse characteristics of the diode shown in Fig.1 is quite realistic, it may not be possible to view it experimentally. The characteristics up to the breakdown point, or close to it, is predicted by the diode equation (1) and the same can be experimentally verified by

(a) using a voltage source of upto 60 volts , the prescribed maximum limit being 65 volts, and,

(b) ensuring that the reverse current will never exceed 1mA, limiting the power dissipation below 50mW so that the diode is not destroyed. Again, the general notion of a constant reverse saturation current, I_o will not be seen in the experimental results, since the reverse current will keep increasing slowly with reverse voltage.

Beyond the breakdown point the physical process drastically changes and the diode equation (1) is no longer valid. This is an unsafe region since the power dissipation in the diode will certainly damage the device and the characteristics may not be evaluated experimentally.

The present setup is designed to operate with ±5V only, which clearly shows the forward characteristics as in Fig.2(a). The reverse characteristics of Fig.2(b) shows currents in the μA region which increases slightly with voltage increases.

2. Boltzmann Constant

In order to avoid uncertainty due to η having any value different from one, we use for the determination of Boltzmann Constant, a transistor (base-collector pn junction of BC-109). Thus with η=1, the diode equation becomes:

$$I = I_0(e^{\frac{qV}{kT}} - 1) \qquad (2)$$

Since $e^{\frac{qV}{kT}}$ increase exponentially with V, we can ignore the second term in equation (2) giving

$$I = I_0 e^{\frac{qV}{kT}} \qquad (3)$$

Taking natural logarithm of equation (3) gives

$$\ln(I) = \ln(I_0) + \frac{q}{kT}V \qquad (4)$$

A graph of ln (I) vs V is a straight line whose slope is given by q/kT. Using the slope we can determine the Boltzmann Constant.

Black – Si
Zener – Silver (transparent) Small
LED
Silver (transparent) big

PROCEDURE

I. Diode and LED Characteristics

(a) Set the selector switch to 'MEASURE' Ger.

(b) Connect the diode in the forward or reverse direction as desired. (See layout Fig. 5)

(c) Set the current range suitably, e.g. 20 mA for forward and 200 μA for reverse characteristics.

(d) Vary the voltage in small steps and record the current. Typical results in Fig 2 (a).

(e) Repeat (c) with the diode reversed. A small current (a few μA) may be observed only in case of germanium diodes. Typical results in Fig 2 (b).

(f) Sketch the V-I characteristics and extend the linear portion of the curve downward to obtain the cut-in voltage V_c. The slope of the linear portion gives the dynamic resistance r_d of the diode.

II Zener Diode Characteristics

(a) Set the selector switch to 'MEASURE'

(b) Connect the zener diode in the reverse direction.

(c) Set current to 200 μA range. Change the range to 20 mA as soon as there is meter overflow.

(d) Vary the voltage in steps of 1 volt and measure the current. Tabulate the readings.

NOTE: For low voltages the reverse current may be too small to be read.

(e) The reverse current would tend to rise steeply after the breakdown (change current range to 20 mA).

(f) Plot the reverse characteristics and obtain from the graph the

- (i) Value of reverse saturation current I_o
- (ii) Zener voltage V_Z
- (iii) Zener resistance r_Z

(g) The forward characteristics of a zener diode may also be plotted as in I above.

III. Boltzman Constant

(a) As explained in theory, perform this experiment using a transistor and its base-collector junction as a diode.

(b) Perform experiment only for forward characteristrics as per steps given in (I). Use base as cathode and collector as anode for npn transistor. Typical results are given in Fig. 3 for BC-109.

CRO DISPLAY

(a) Connect the X, Y and ground terminals on the panel to a CRO in x-y mode. Set the sensitivity to 1 cm/V for both channels.

(b) Set the selector switch to CRO display. The x and y axes should be displayed.

(c) Connect the diode in the appropriate terminals in forward/reverse mode as desired.

(d) A CRO display of the characteristics will be seen. Typical traces are given in Fig 3 (a), (b) & (c). Rough measurements are possible on the screen since the x and y axes are calibrated to 7V and 70mA respectively.

(e) The y-display however has been limited to 5V

PRECAUTIONS

(a) Set the current switch properly. An incorrect setting may not give accurate readings.

(b) To sketch the characteristics accurately near the sharp bends (around the cut-in and breakdown points) a larger number of readings may be necessary.

TYPICAL RESULTS

I. Germanium Diode (Type 1N34)

(a) Forward Characteristics (V, Volts vs. I, mA)

V (V)	0.00	0.10	0.20	0.30	0.40	0.60	0.80
I (mA)	0.00	0.04	0.26	0.62	1.09	2.26	3.87
V (V)	1.00	1.25	1.50	1.75	2.00	2.25	2.40
I (mA)	5.24	7.37	9.58	12.14	14.8	17.91	19.77

(b) Reverse Characteristics

V (V)	0.00	0.10	0.20	0.30	0.40	0.60
I (μA)	0.0	1.3	1.4	1.5	1.6	1.8
V (V)	0.80	1.00	1.20	1.40	1.60	2.00
I (μA)	2.0	2.1	2.3	2.5	2.7	3.0

II. Zener Diode (Type 3.9V)

(a) Forward Characteristics

V (V)	0.00	0.25	0.50	0.60	0.65	0.70	0.75	0.77	0.78	0.79
I (mA)	0.00	0.00	0.01	0.03	0.12	0.53	3.33	6.34	9.23	15.95

(b) Reverse Characteristics

V (V)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.30
I (mA)	0.000	0.000	0.000	0.002	0.020	0.123	0.540	1.190
V (V)	3.50	3.60	3.70	3.80	4.00	4.10	4.20	
I (mA)	1.990	2.520	3.250	4.160	6.970	9.180	12.290	

The above characteristics are plotted in Fig. 2(a), (b), (c) & (d). A variation of 20% in the readings is normal in semiconductor devices of the same type number.

Fig 2(a): Forward Characteristics

Sample: Germanium Diode (IN34)

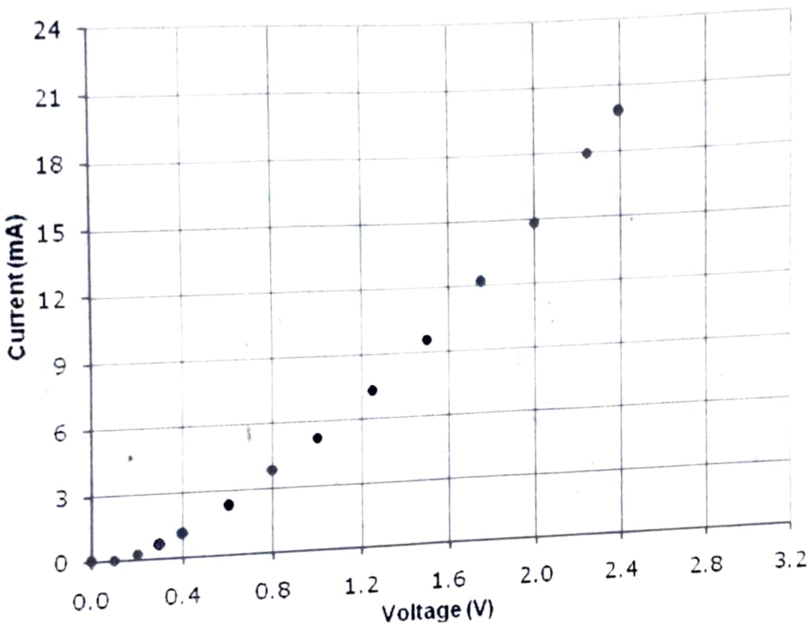


Fig. 2(b): Reverse Characteristics

Sample: Germanium Diode (IN34)

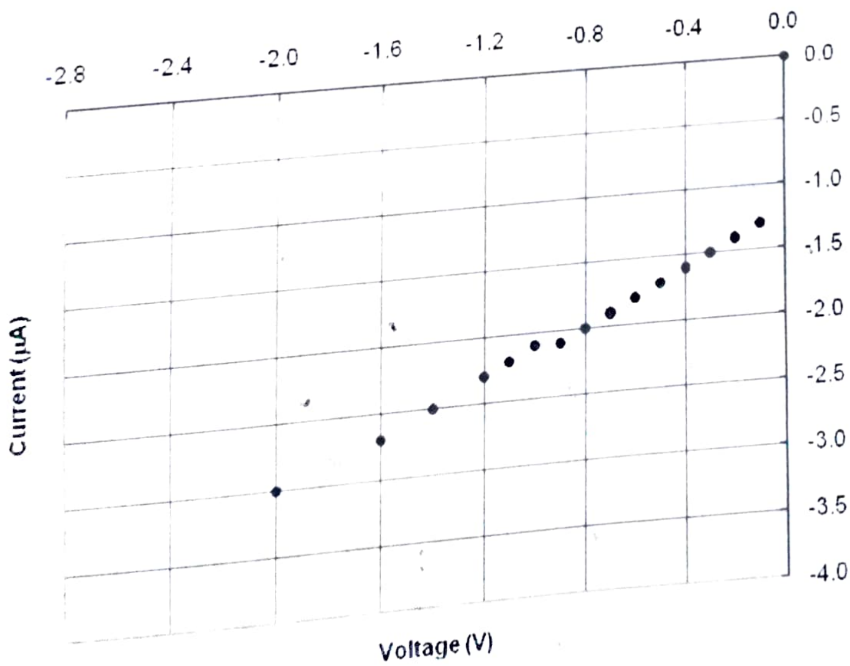


Fig. 2 (c) Forward Characteristics

Sample : Zener Diode (3.9V)

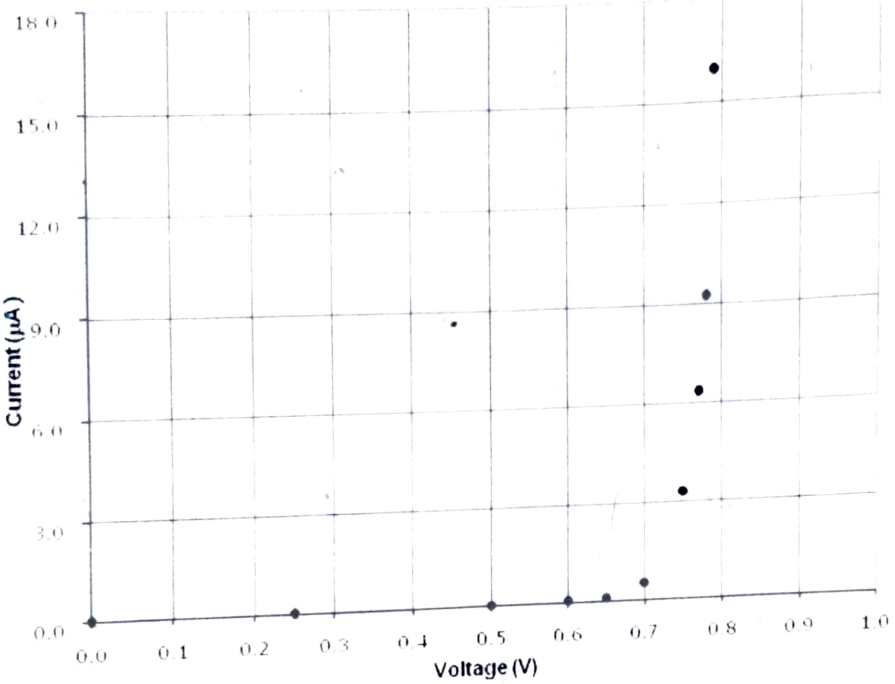
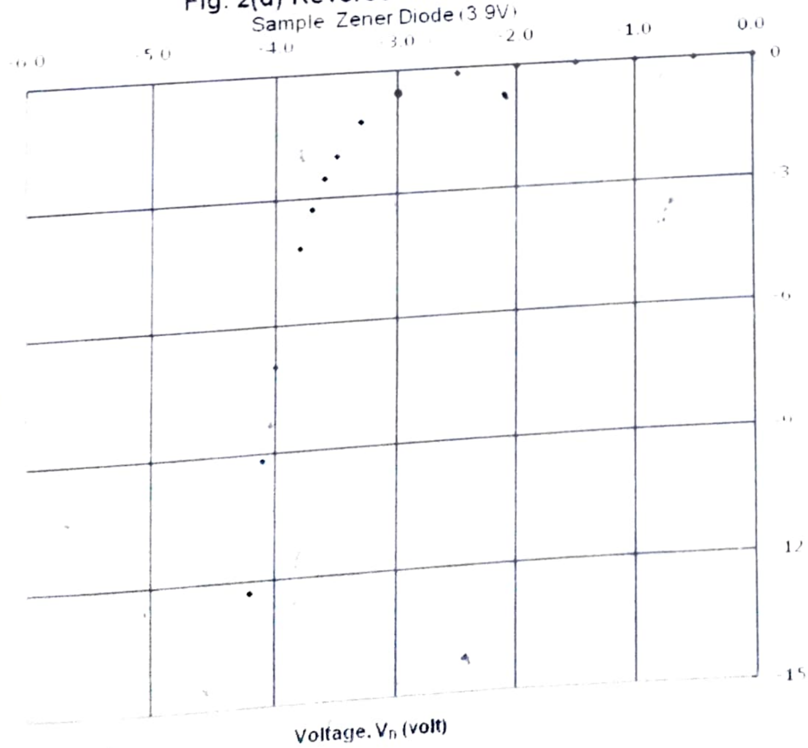


Fig. 2(d) Reverse Characteristics

Sample Zener Diode (3.9V)



III Boltzmann Constant

S. No	Voltage (V)	Current (μA)	lnI (μA)
1	0.44	0.3	1.20
2	0.45	0.4	-0.92
3	0.46	0.6	-0.51
4	0.47	0.9	-0.11
5	0.48	1.4	0.34
6	0.49	2.0	0.69
7	0.50	3.1	1.13
8	0.51	4.0	1.39
9	0.52	5.8	1.76
10	0.53	8.3	2.12
11	0.54	11.1	2.41
12	0.55	16.0	2.77

Room temperature 26°C

Slope of the straight line graph in Fig. 3 = 36.9 $volt^{-1}$

It is equal to q/kT

therefore $k = \frac{q}{(26 + 273) \times 36.9}$

$= \frac{1.6 \times 10^{-19}}{299 \times 36.9}$

$= 1.45 \times 10^{-23} JK^{-1}$

Standard value of $k = 1.38 \times 10^{-23} JK^{-1}$

Error = 5.1%

Slope = $\frac{q}{kT}$

$36.9 = \frac{q}{kT}$

$\Rightarrow K = \frac{q}{T \times 36.9}$

IV. CRO display of the forward characteristics of the Germanium and LED diodes is shown in Fig. 4(a) and 4(b) and forward and reverse characteristics of Zener diode is shown in Fig. 4(c) and 4(d)

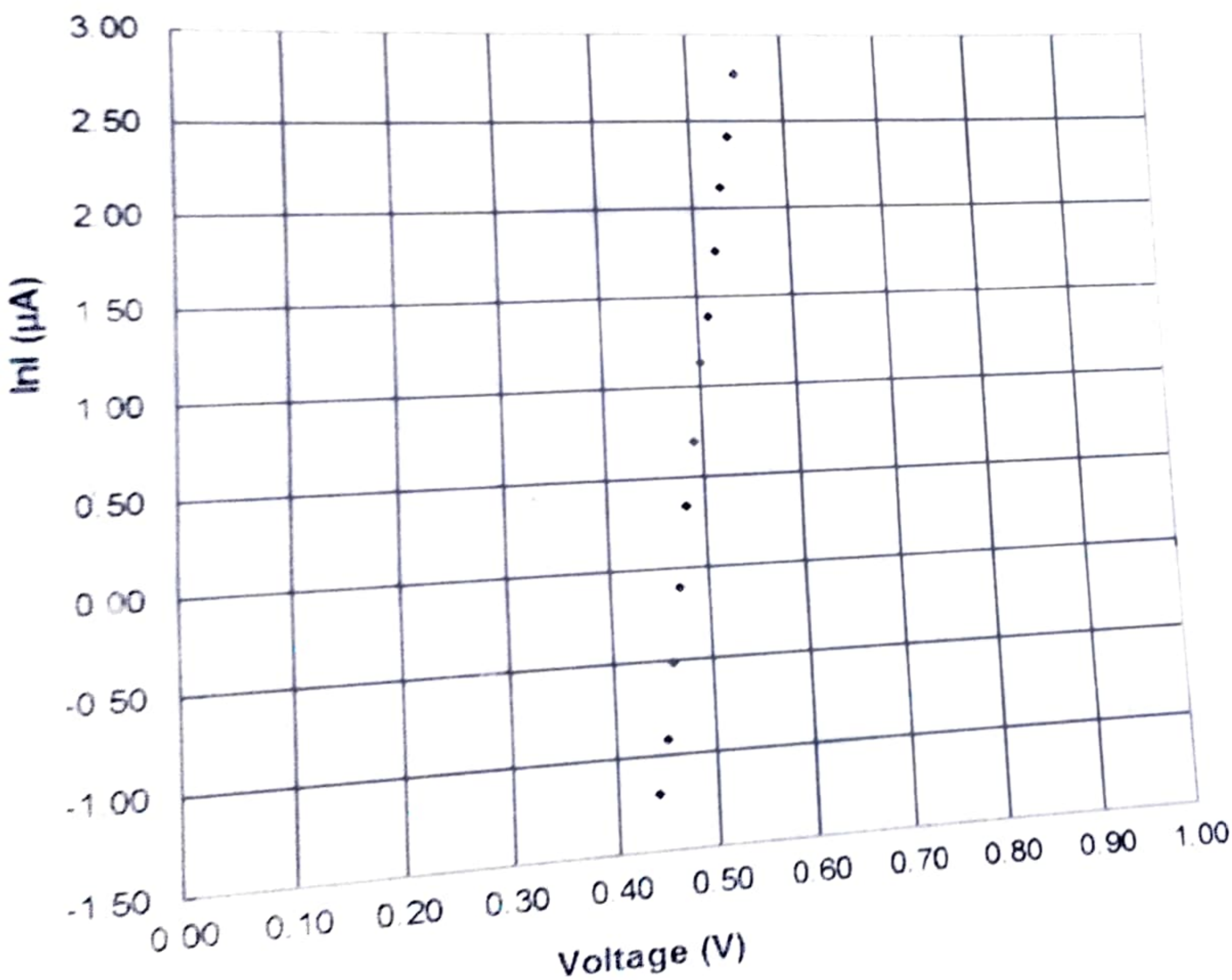
Note

a) Since the device current in all cases is limited to a safe value by the circuit. The waveform displayed has a flat section (X) which is not a part of the characteristics

b) The reverse characteritics of zener diode though shown in the first quadrant essentially lies in the third quadrent

Fig. 3: Boltzmann Constant

Sample Transistor BC-109



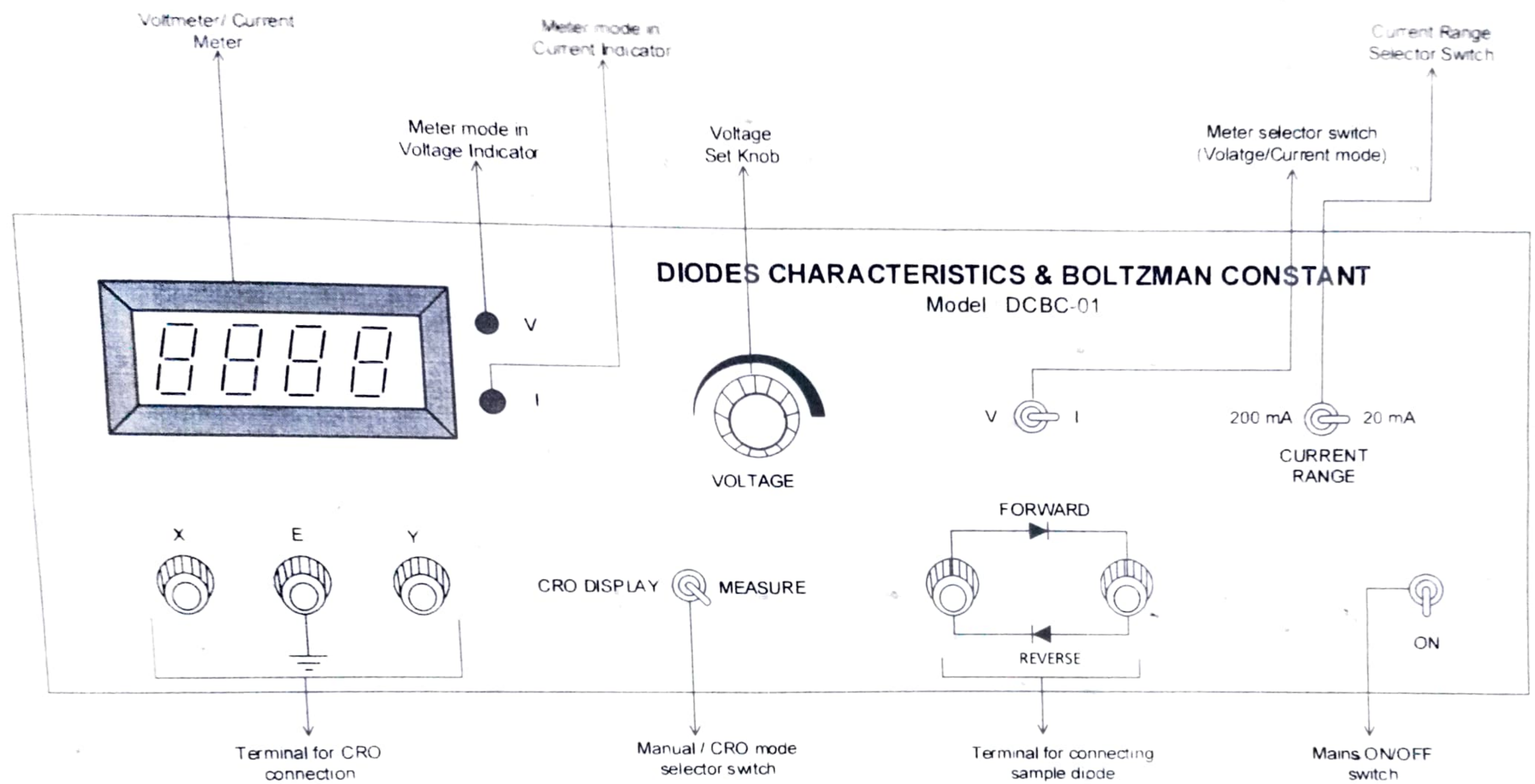


Fig 5: Panel diagram of Study of Diode Characteristics & Boltzman Constant, DCBC-01