Experiment Number

To find out the energy band gap of a semiconductor by four probe method.

Learning Objectives

1. **To measure the resistivity of a semiconductor material using four probe method.**

2. **To study the temperature variation of resistivity of a semiconductor material.**

3. **To find out the energy band gap of a semiconductor.**

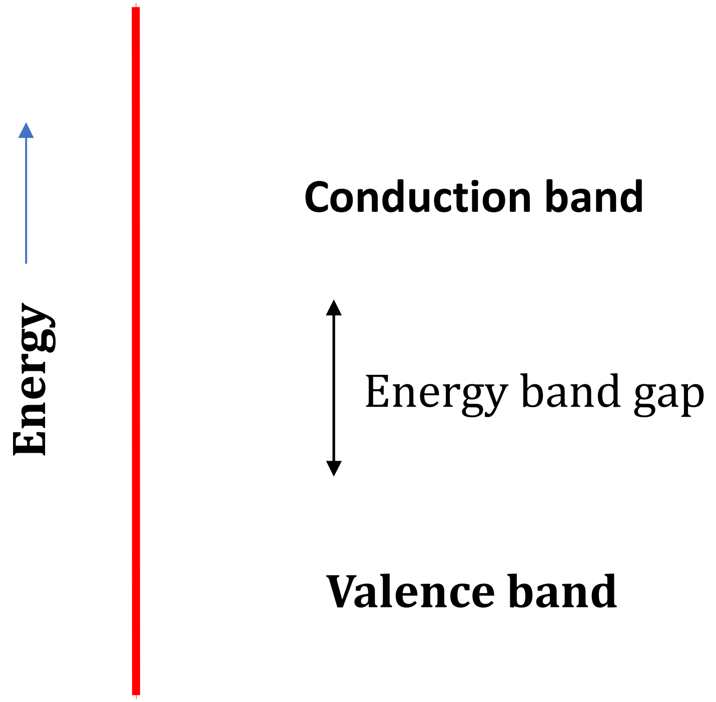
The student will also be able

1. To visualize the position of the four probes on the sample in the virtual lab environment.
2. To select the range and values of different variables to conduct the experiment.
3. To find out the values of the voltage across the sample, while passing a fixed amount of current, at different measuring temperature.
4. To calculate resistivity of the sample under consideration from the simulator data.
5. To understand the temperature variation of resistivity of a semiconductor sample by plotting suitable graph.

Basic Understandings

Semiconductor

- ❖ Semiconductors are materials which have electrical conductivities lying between good conductors and insulators.
- ❖ Elemental semiconductors such as silicon germanium belongs to the Group IV of the periodic table.



- ❖ Natural pure form of a semiconductor is known as intrinsic semiconductor.
- ❖ Conductivity is mainly to due thermally generated charge carriers.
- ❖ Electron hole pair generation on breaking of a covalent bond.

Semiconductor wafer

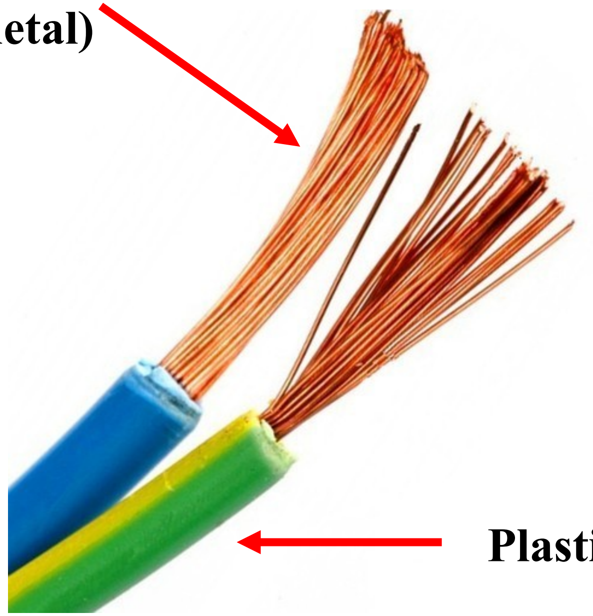
Electronic configuration of Ge: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^2$
Electronic configuration of Si : $1s^2 2s^2 2p^6 3s^2 3p^2$

Metals , Semiconductors, Insulators

Germanium or Silicon
(semiconductor)

Wood
(insulator)

Copper
(metal)



Resistivity ranges (approx.)

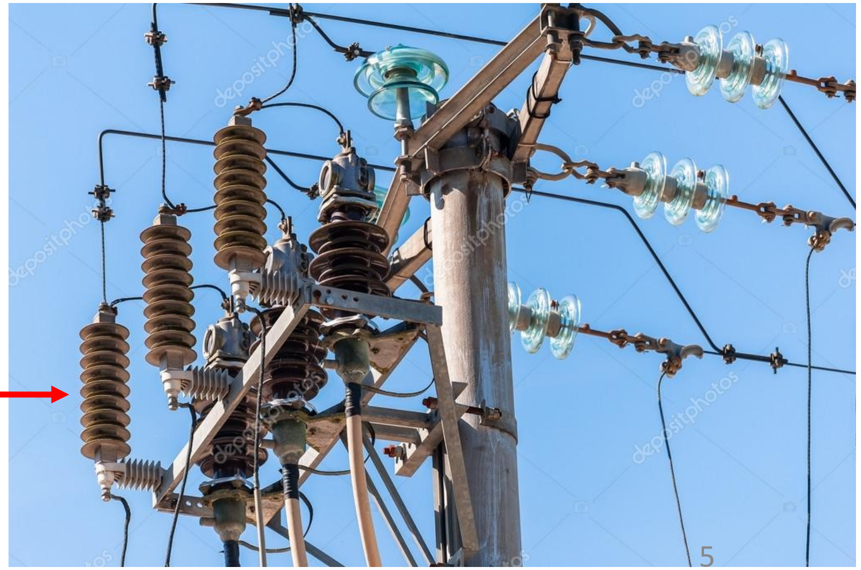
Conductors: 10^{-8} to 10^{-6} ohm-m

semiconductors: 10^{-5} to 10^{4} ohm-m

Insulator: 10^{7} to 10^{8} ohm -m

Plastic (insulator)

Ceramic insulator



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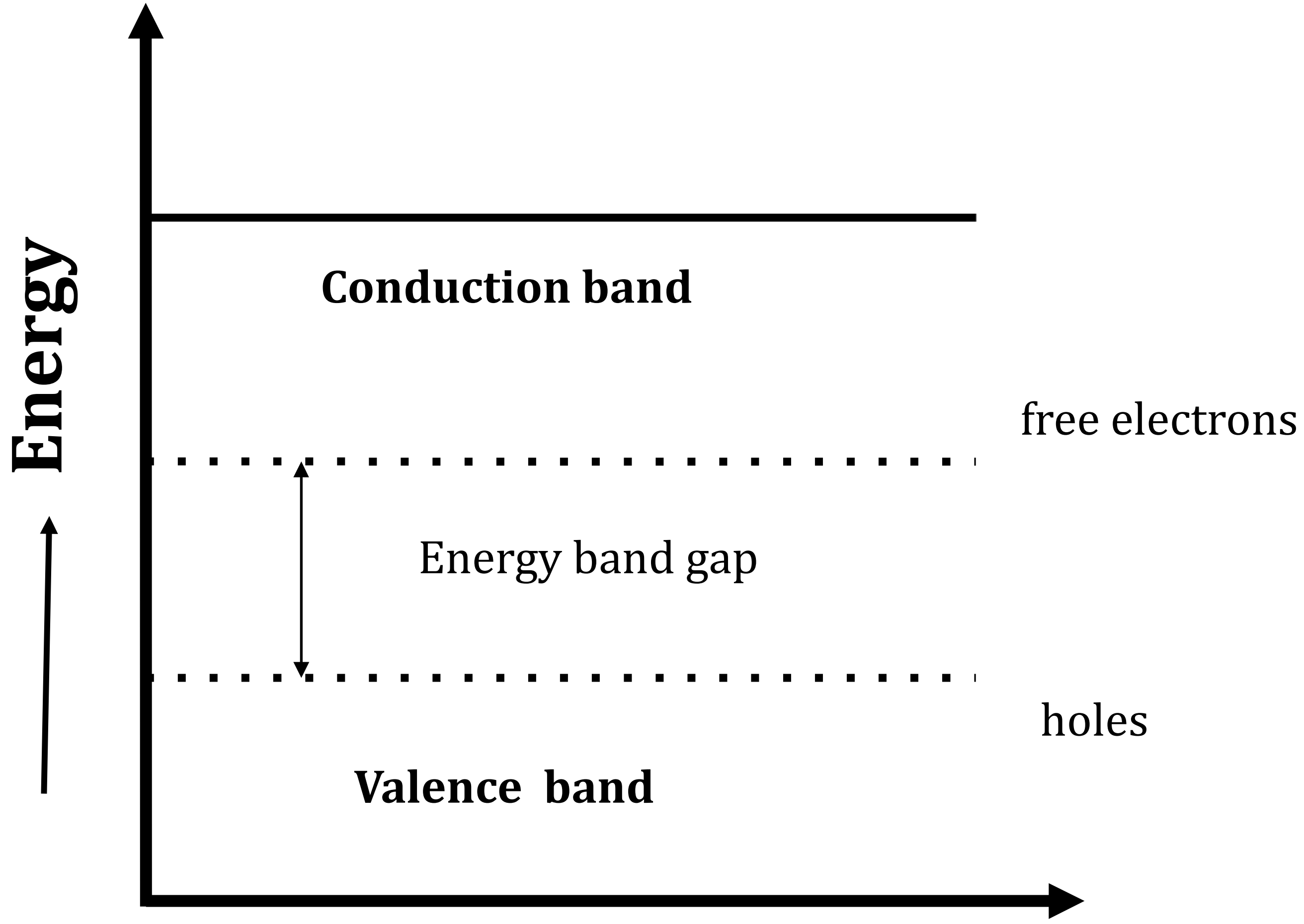
Energy band gap



- **The energy difference between the valence band and conduction band is called <u>band gap.</u>**

- **In case of semiconductors the energy gap between filled valence band and empty conduction band is <u>small compared to insulators but more as compared to conductors.</u>**

The band gap of semiconductor varies from 0.2 to 2.5 eV. For Germanium it is ~0.67 eV. whereas the bandgap of a typical insulator (diamond) 6 eV.

- **Due to small energy band gap between the valence band and conduction band ,the electrons of valence band can be thermally excited to the conduction band.**

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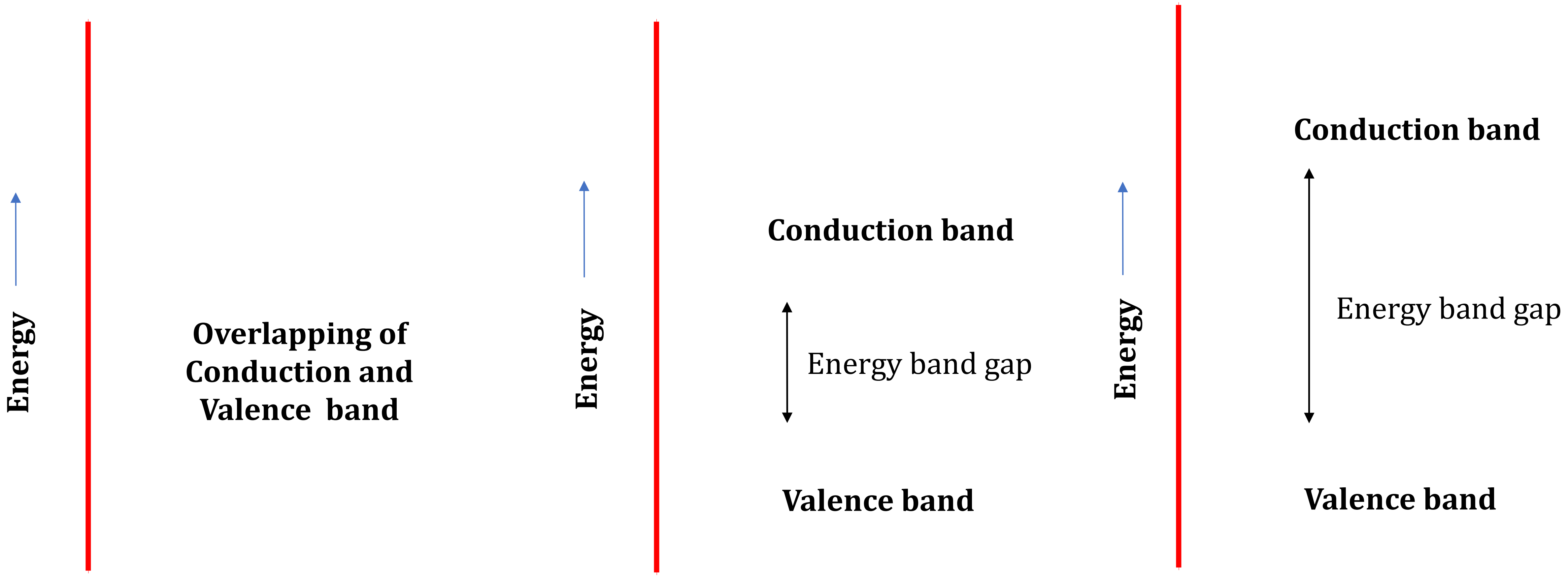
Metal, Semiconductor and Insulator



Metal **Semiconductor** **Insulator**

*Energy not to scale

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Calculation of energy band gap of a semiconductor from the temperature variation of resistivity

The resistivity (ρ) of a semiconductor sample can be expressed as -

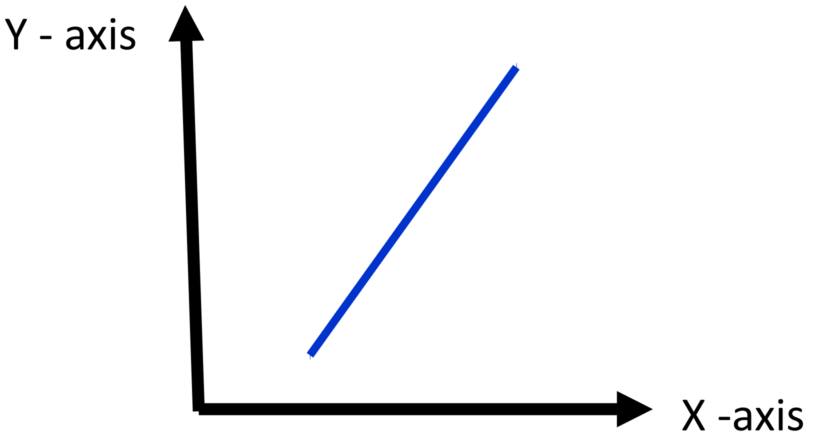
Where Eg is Band Gap in eV, *k* is Boltzmann constant =8.617×10^{-5} eVK^{-1} , T is absolute temperature in Kelvin

The constant A depends on carrier concentrations and mobility of the charge carriers (electrons and holes)

Taking natural logarithm on both side of equation (i)

(B is another Constant)

Or



So by plotting a graph between log ρ versus 1000/T we can find out the slope and hence the energy band gap of the semiconductor material.

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Check your understanding

Q

Q1.1 : Which of the following statement(s) is (are) true about semiconductors:

(A) there is a small energy gap between the valence band and conduction band

(B) valence band and conduction band overlap with each other.

(C) electrons of valence band can be thermally excited to the conduction band.

(D)both the options (A) and (C)

Check your understanding

Q

Q1.2 : The display panel of a temperature sensor indicates 45 °C. The corresponding temperature in Kelvin is

(A) 228 K
(B) 273 K
(C) 308 K
(D) 318 K

Check your understanding

Q

Where A is a constant, Eg is Band Gap in eV, *k* is the Boltzmann constant =8.617×10^{-5} eVK^{-1} , T is absolute temperature in Kelvin

Check your understanding

Q

Q1.4 : With increase in temperature, the conductivity ($\sigma = 1/\rho$) of the semiconductor sample

(A) decreases
(B) increases
(C) remains constant
(D) suddenly drops to zero

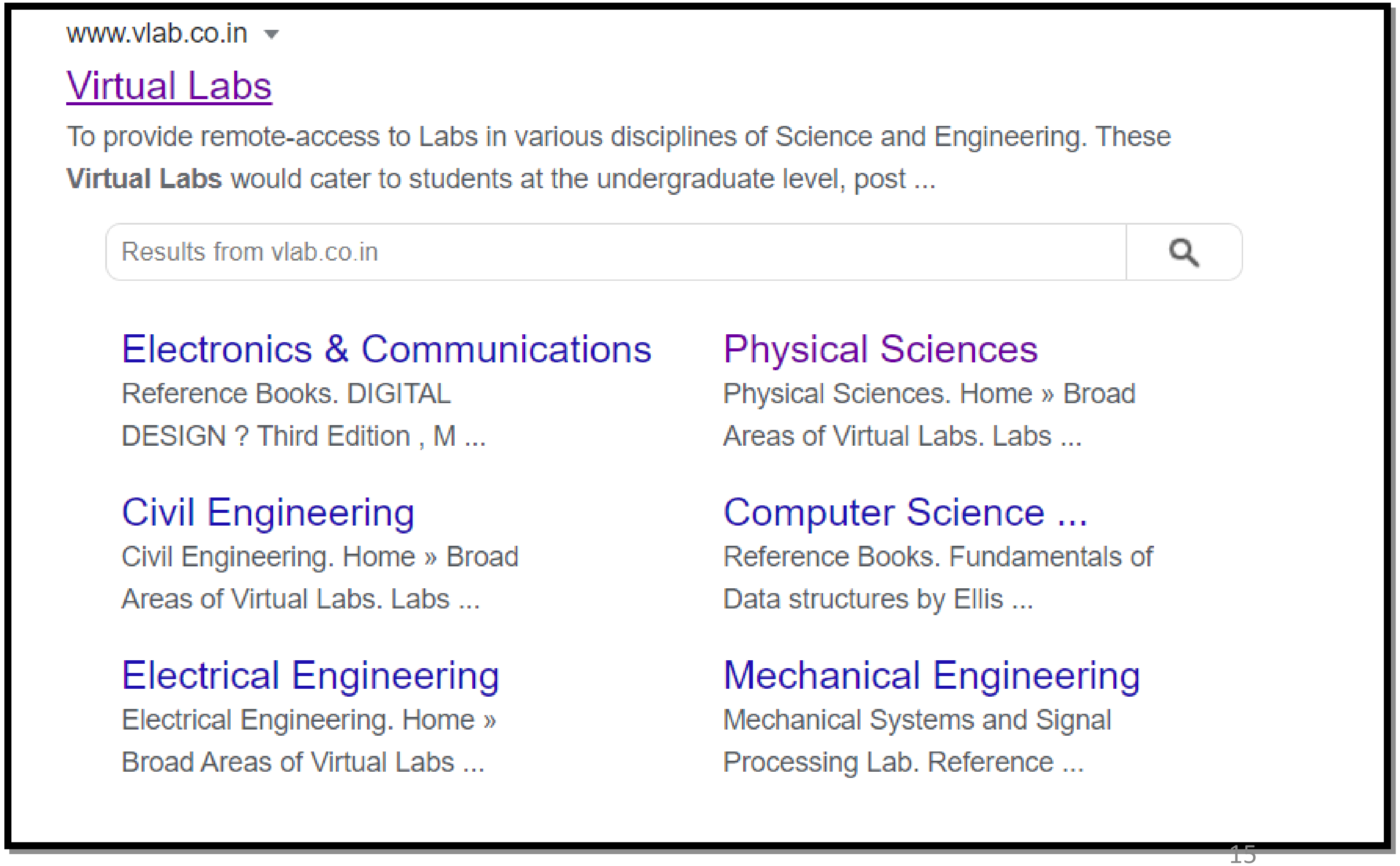
Q

Q1.5 : Unit of energy band gap is

(A)Electron volt
(B) Coulomb
(C) Volt/meter
(D) Joule/second

Step by Step guide to perform the experiment in Virtual lab

Type this link on the address bar or Click on this link : https://www.vlab.co.in/



This page will open. Scroll down the page end click on Physical sciences

Scroll down the page end click on Physical sciences

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- Civil Engineering
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DAYALBAGH EDUCATIONAL INSTITUTE

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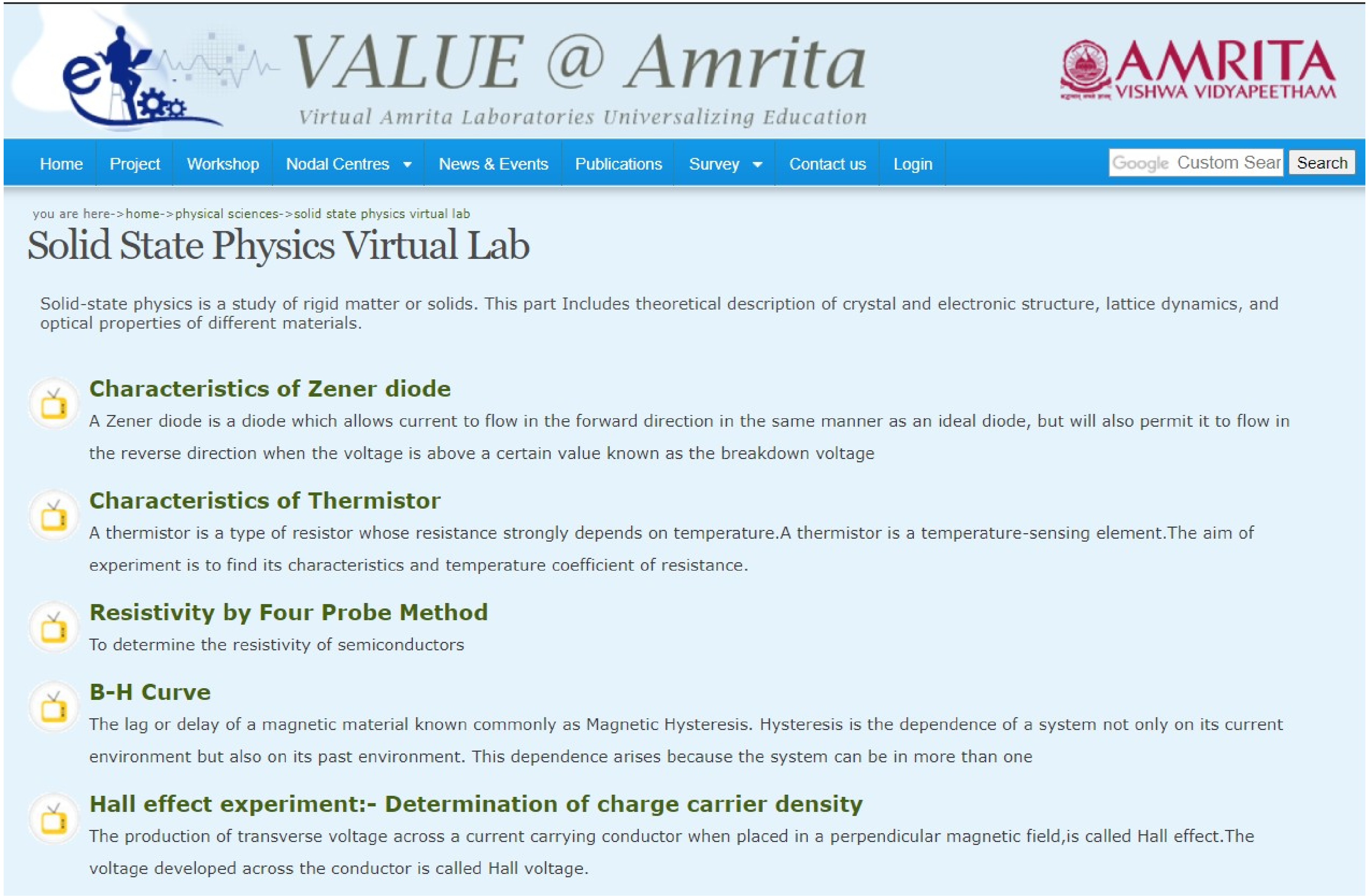
Announcements

* **4th edition of Virtual Labs Newsletter is released**. *Please click here to download.*

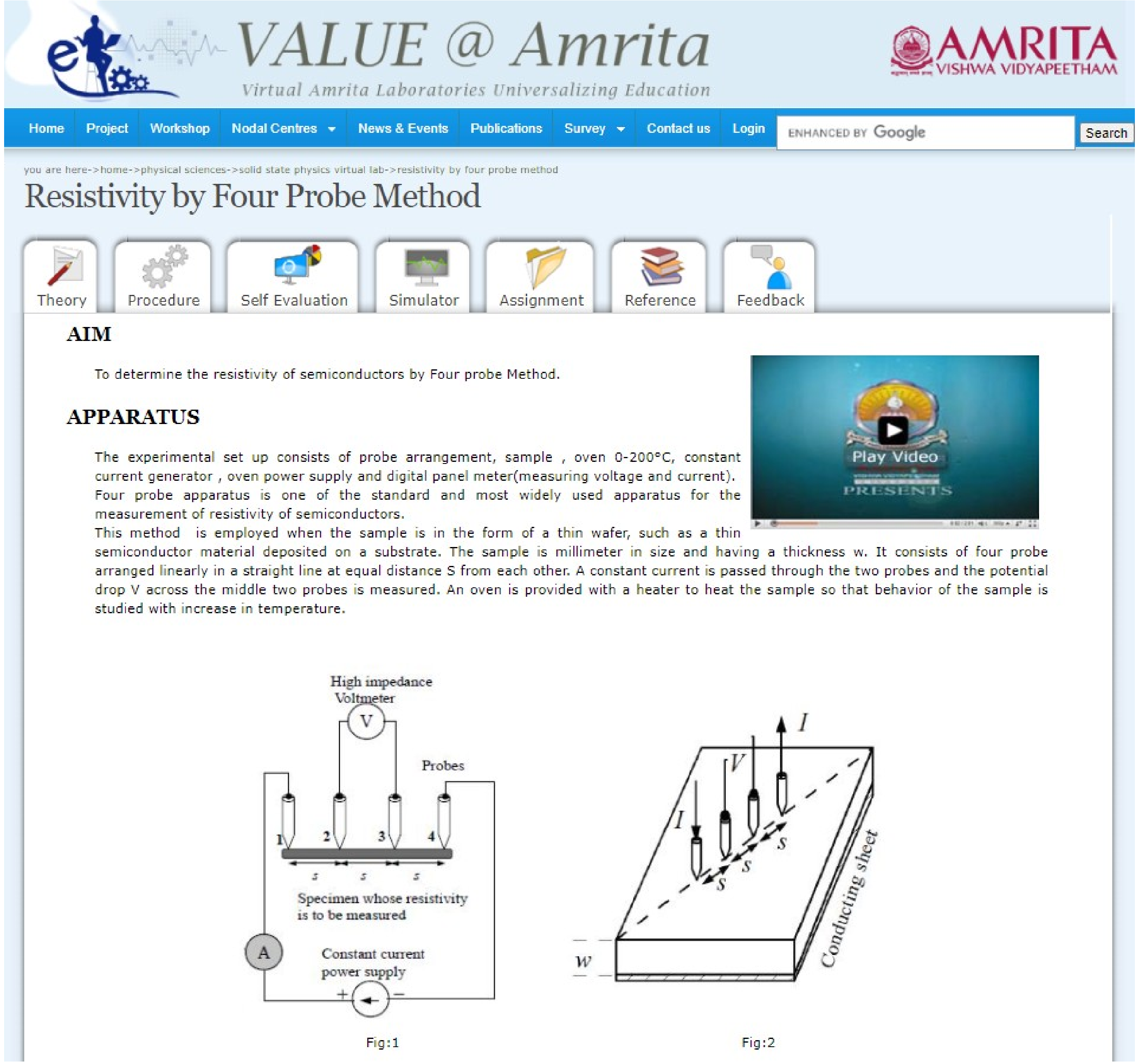
* Various projects/ICT initiatives of MHRD are available on the link given here. **Please click here for more**

Then click on – Resistivity by Four probe Method



Details of the experiment will be available to you . You may login also.

- **Read the theory**
- **Procedure**
- **Complete the self evaluation to check your understanding**
- **Then click on the simulator**

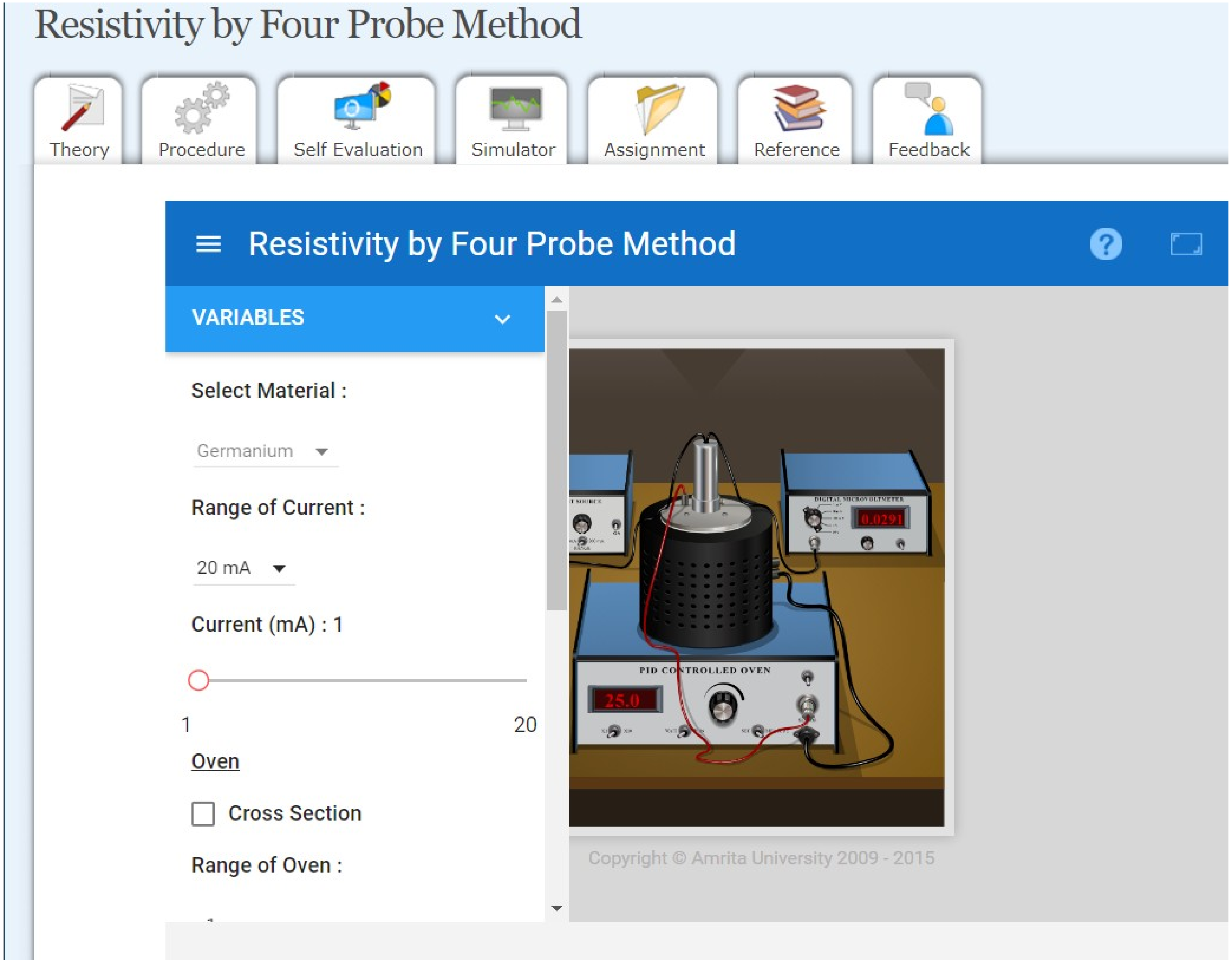


When Click on the simulator , this page will be visible

Then click here to open the list of variables

the list of variables is available now.

But it covers some portion of the oven and you have to toggle the show variables option while performing the experiment.



Resistivity by Four Probe Method

Theory | Procedure | Self Evaluation | Simulator | Assignment | Reference | Feedback

Resistivity by Four Probe Method

VARIABLES

Select Material :

Germanium

Range of Current :

20 mA

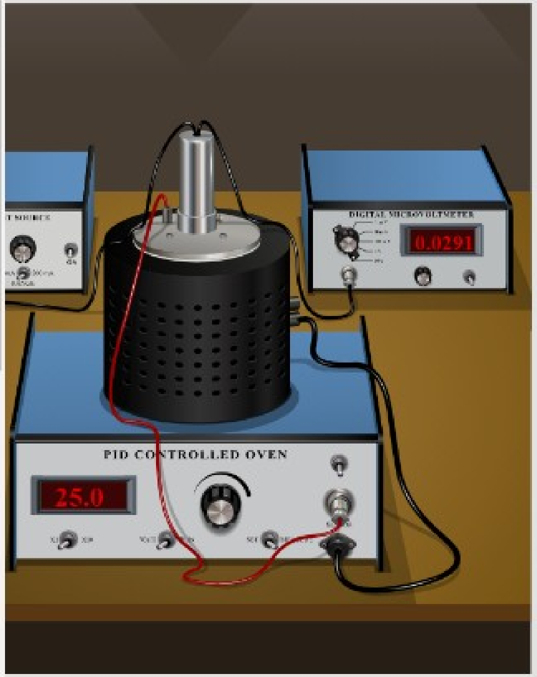
Current (mA) : 1

1 20

Oven

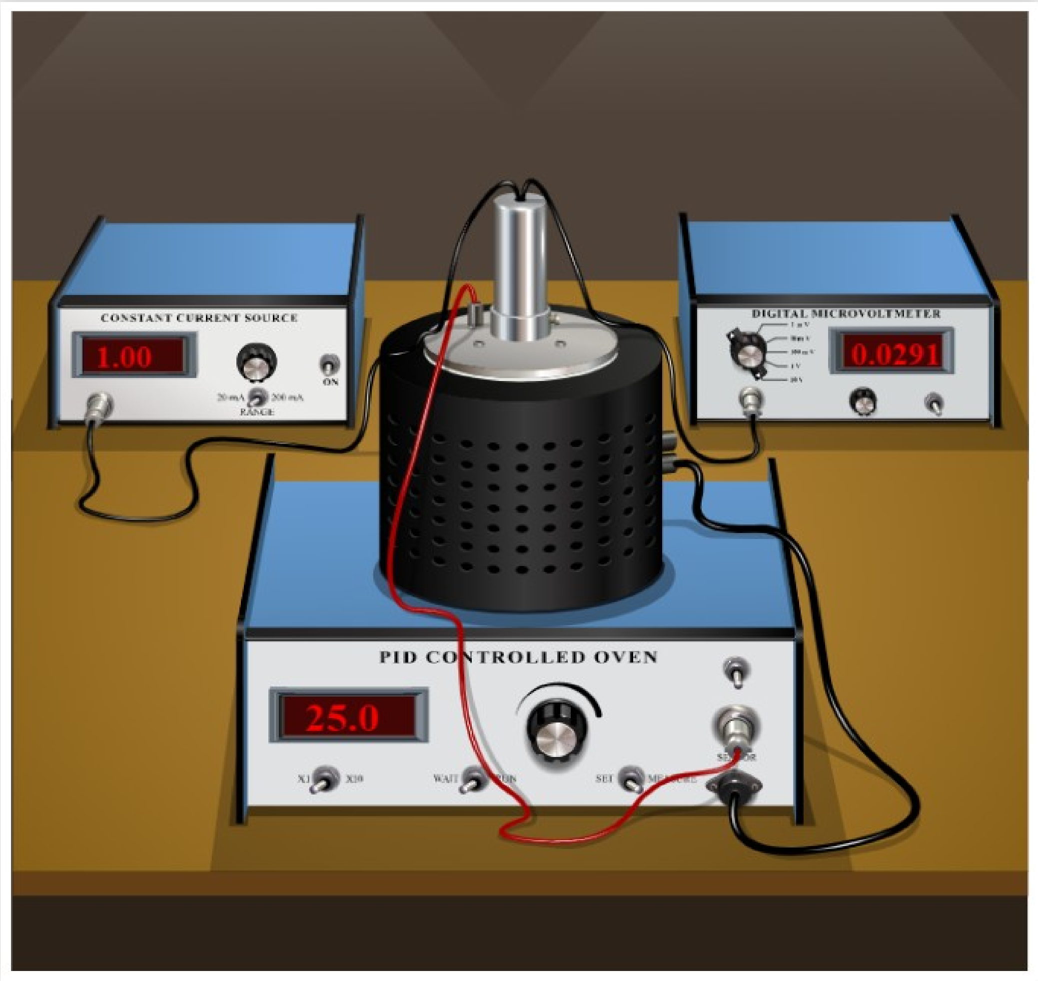
☐ Cross Section

Range of Oven :



Click here to zoom

When Click on the simulator , this page will open



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the list of variables is available now conveniently

VARIABLES

Select Material :

Germanium

Range of Current :

20 mA

Current (mA) : 1

1 20

Oven

Cross Section

Range of Oven :

x1

SET MEASURE

RUN WAIT

Temperature (°C) : 25

25 95

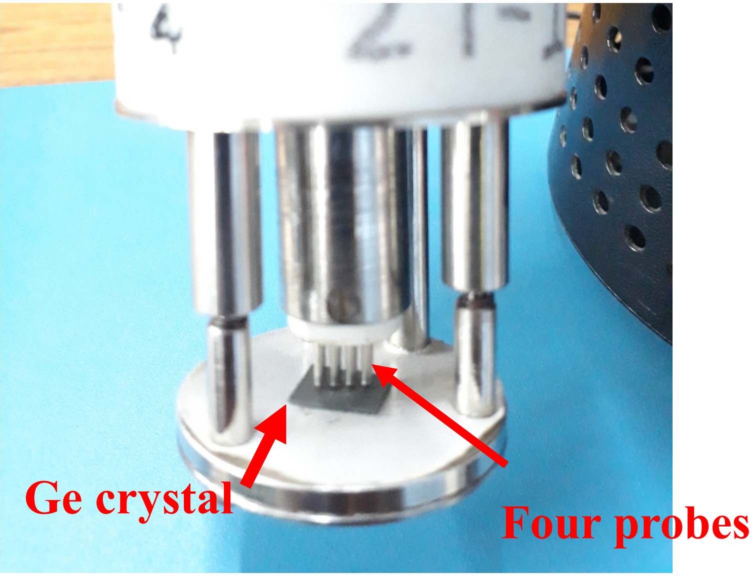
Range of Voltmeter :

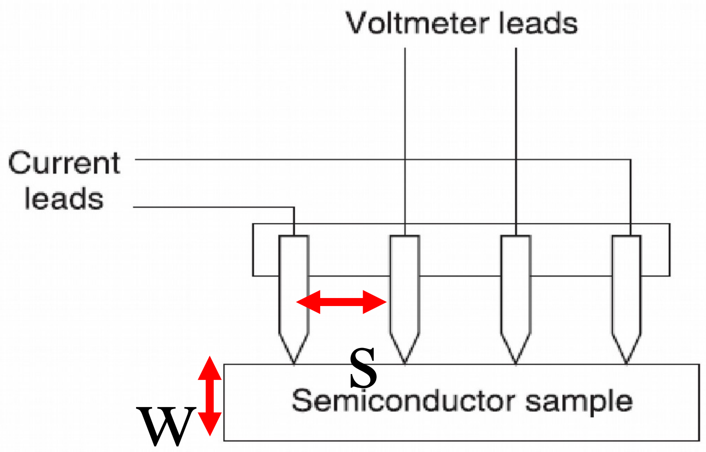
10 V

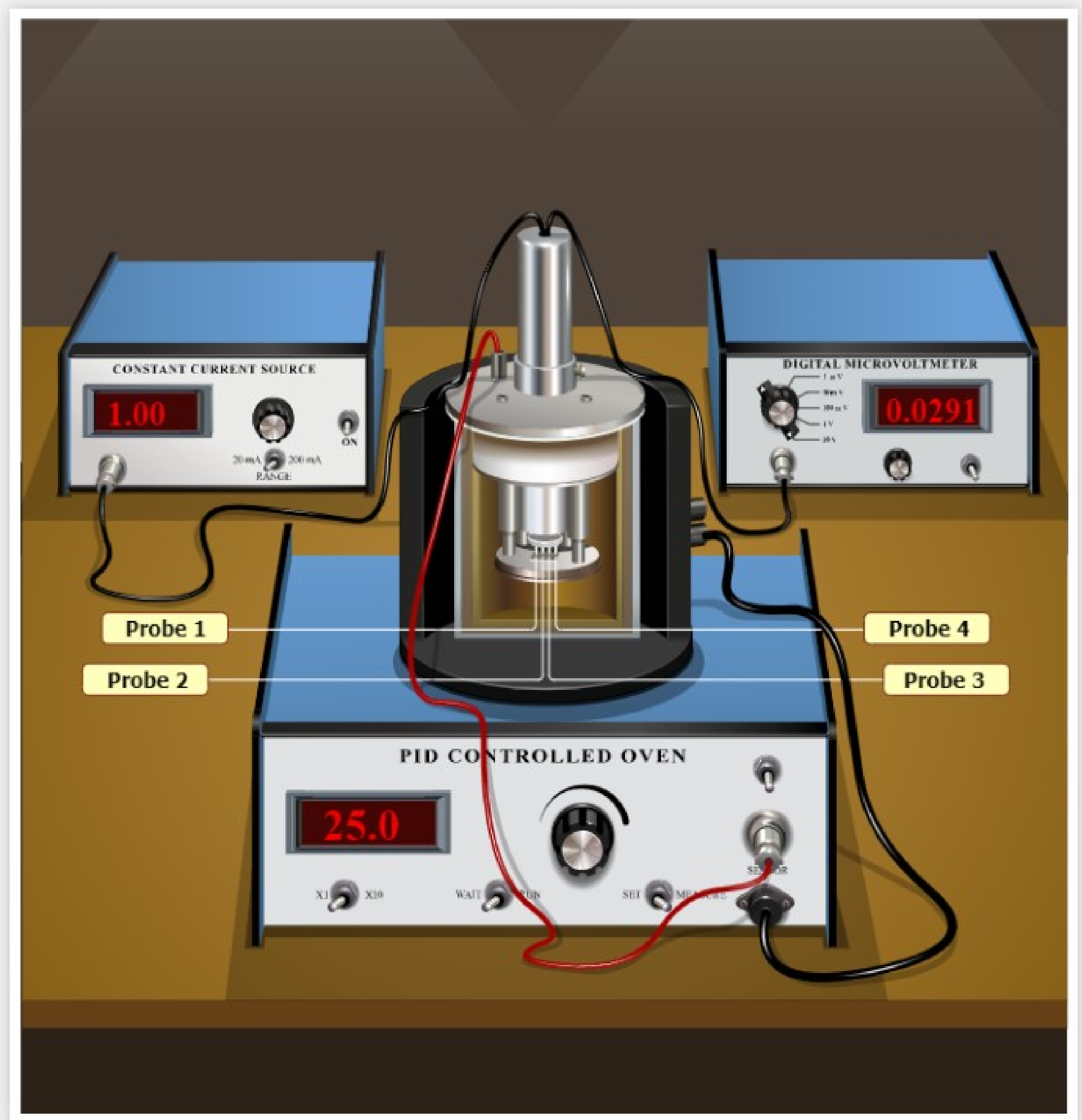
RESET

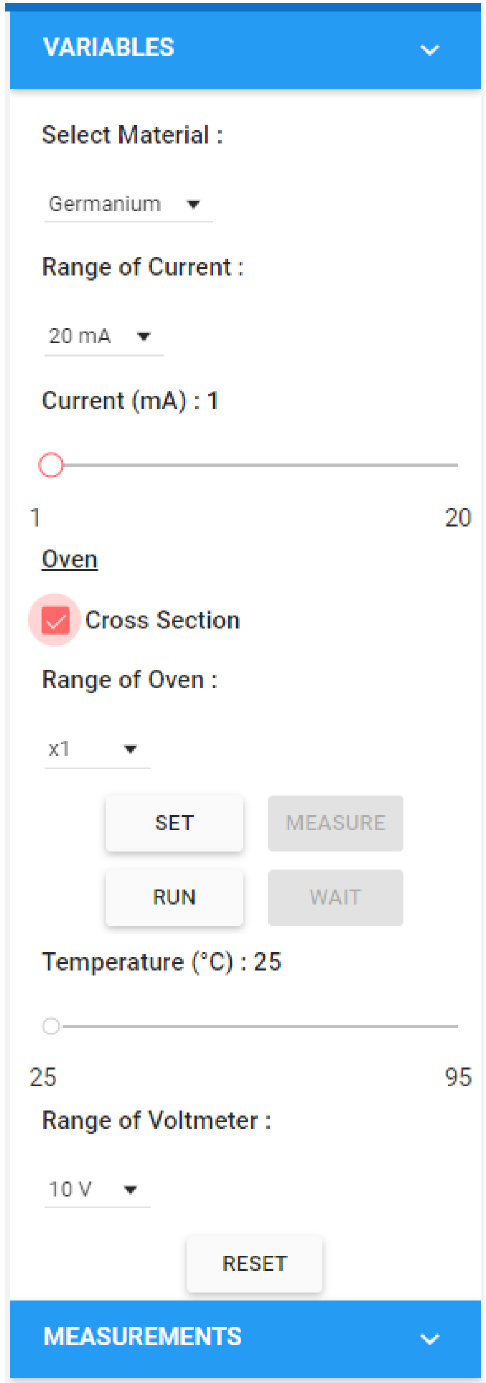
MEASUREMENTS

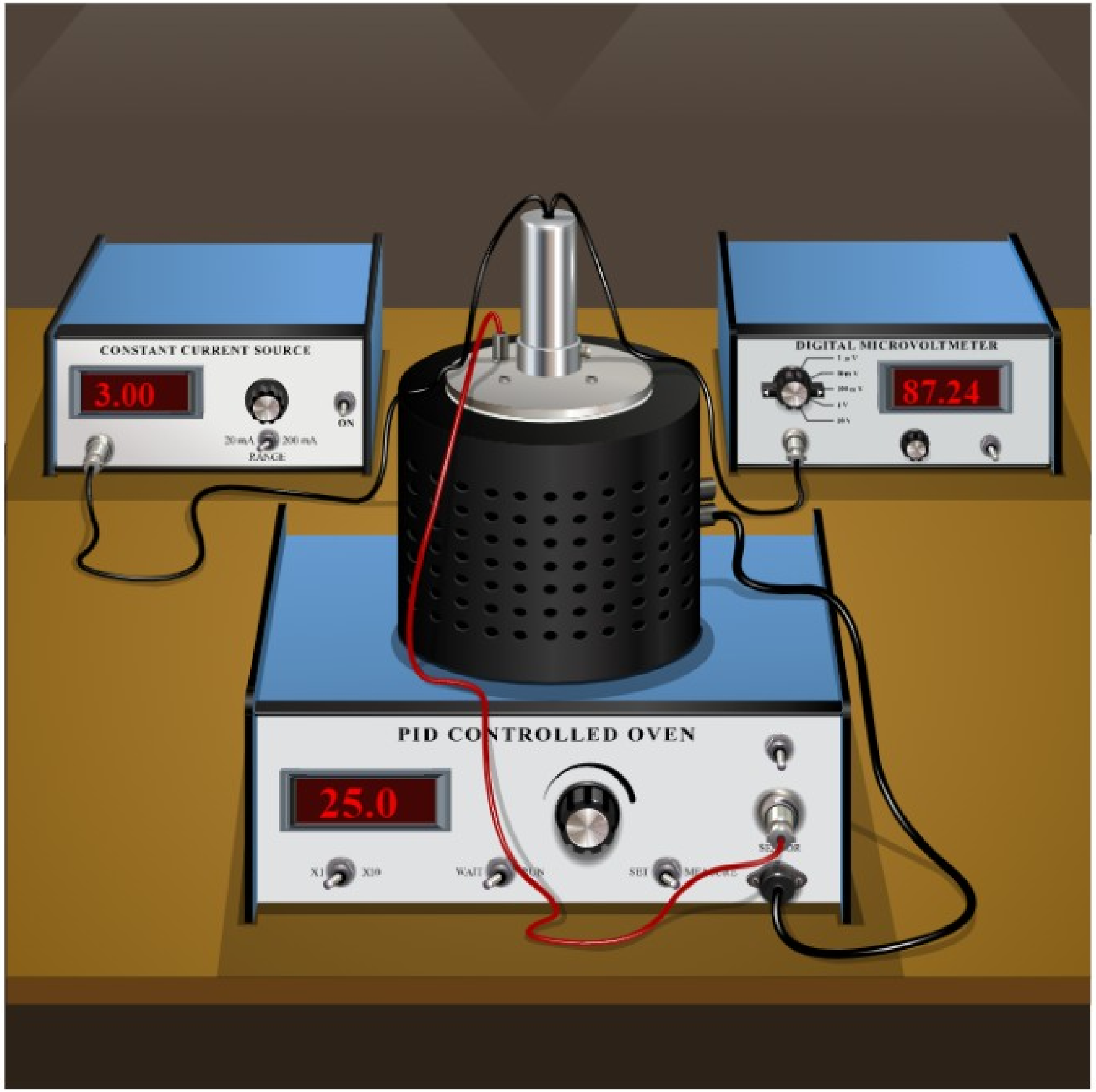
Click on the cross section checkbox to see the probes

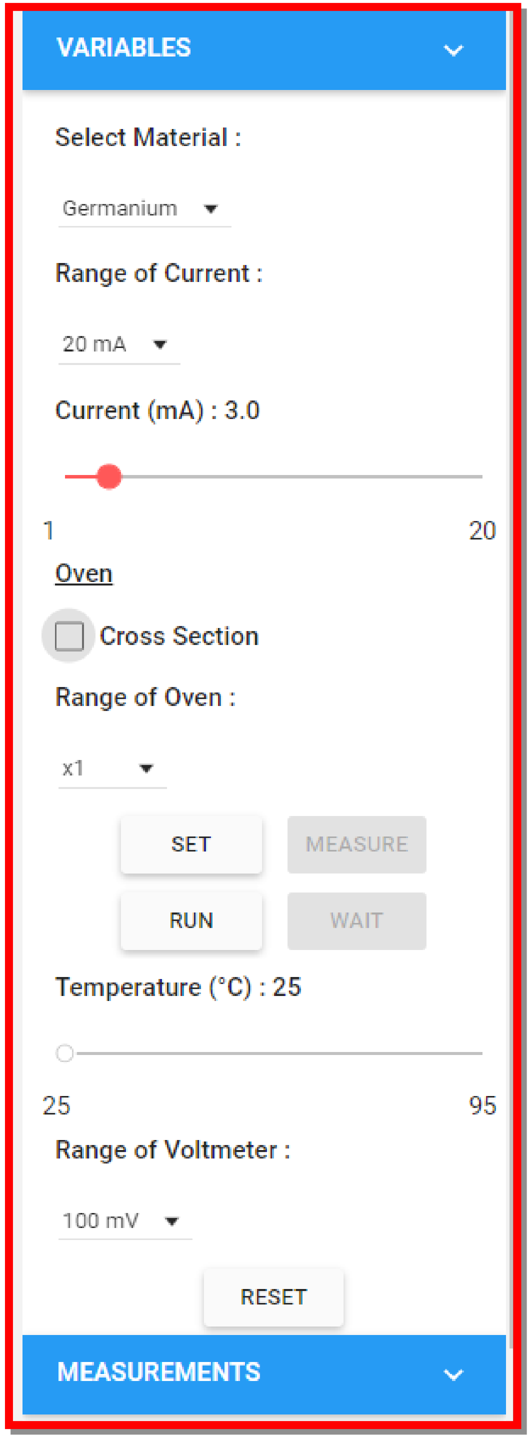












Selection of the variables

Select the material from the drop down button. Either Silicon or Germanium. Select Germanium here. Then Select the range of current to 20 mA

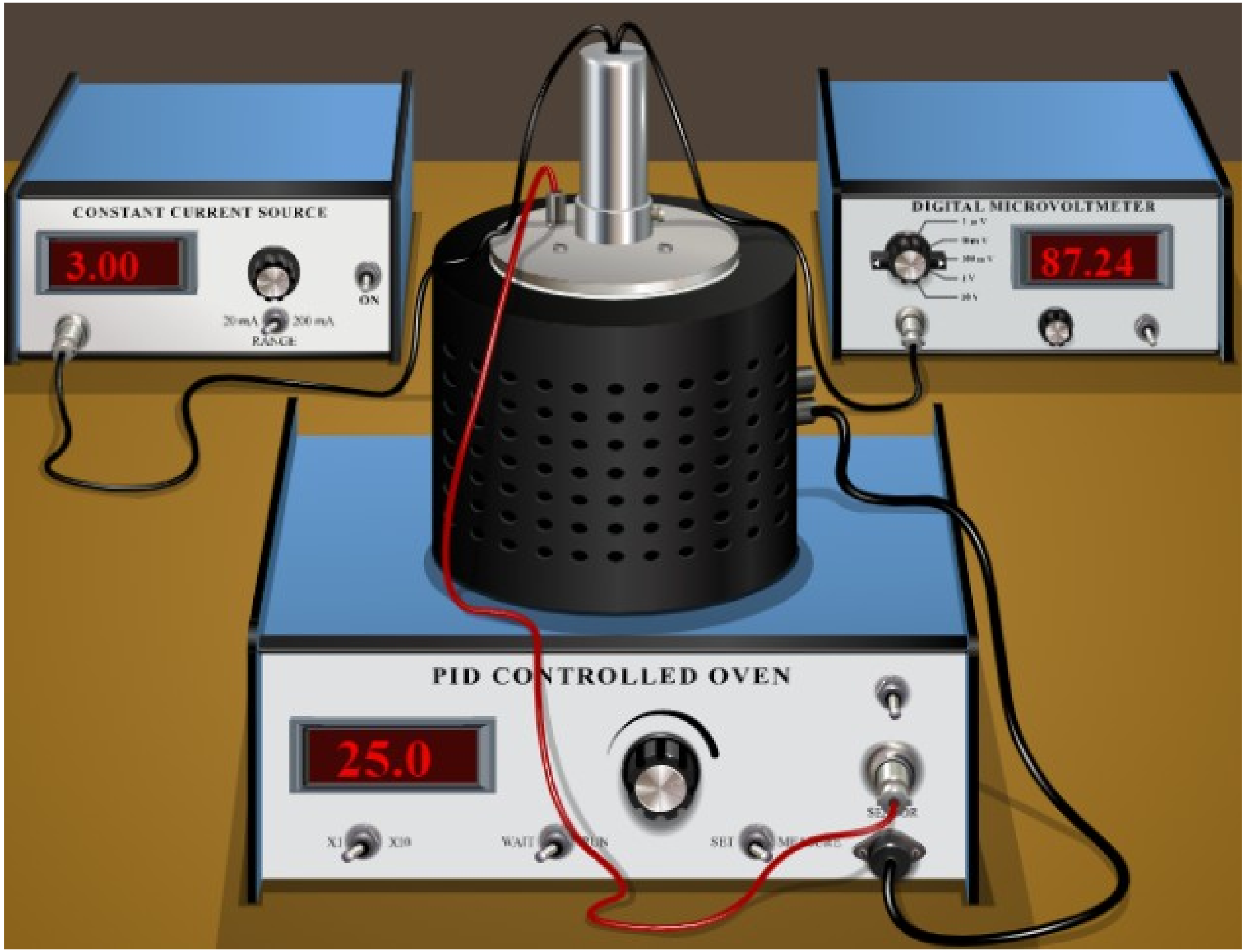
Set the current to say 3 mA

Set the range of the oven to x1 or 10 (as required)

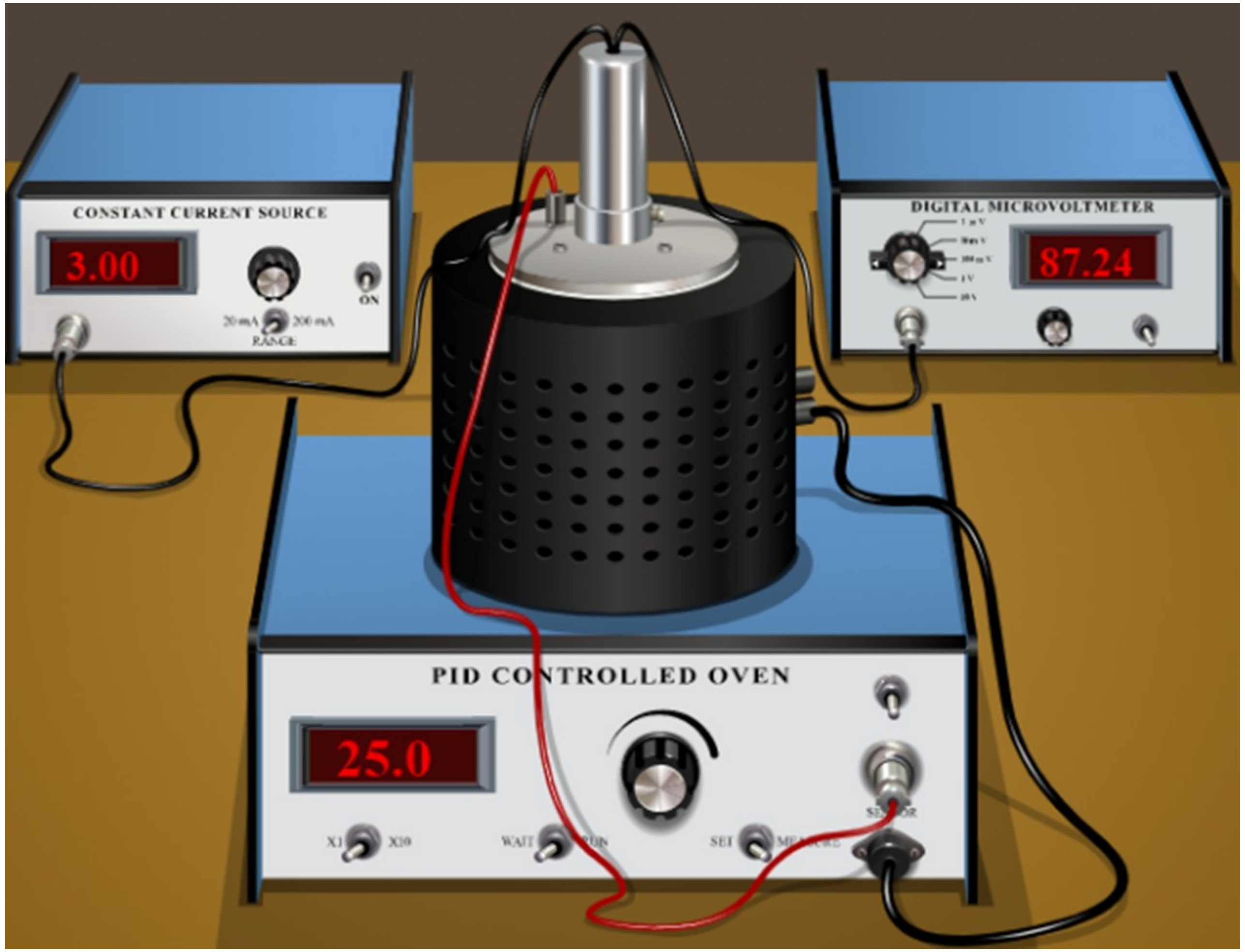
Set the range of the voltmeter to 100 mV from the drop down options

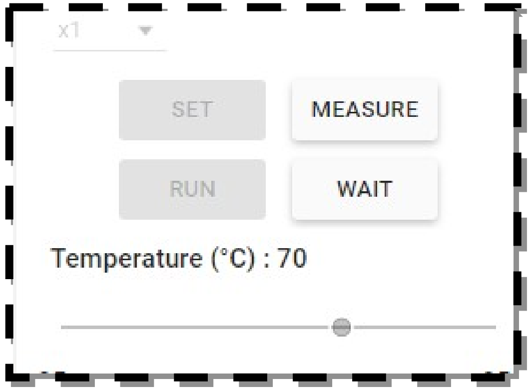
If you want to change the input values, only then click ‘Reset’ otherwise you are good to start the experiment.

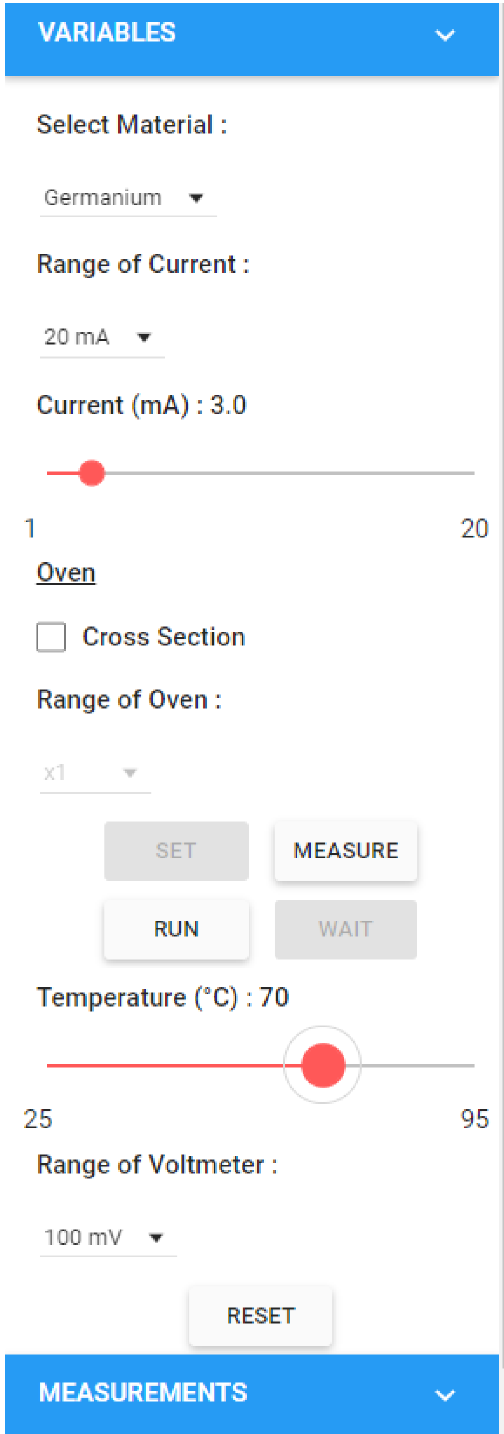
Next you have to set the temperature of the oven and run it.



Note: Convert the temperature from degree centigrade to Kelvin. Say if we want to perform the experiment from 25 °C to 70 °C. with step of 5 °C . Then write the temperature values in the worksheet column accordingly in Kelvin (adding 273 to °C).







Then Click on “Set” and set the temperature (say to 70 °C) by sliding the temperature bar.

Then Click on “Run”

Oven temperature will now increase. Check the oven display panel and click ‘’wait’ to note down the millivoltmeter readings (in the worksheet) at each 5°C (or 5K) interval up to 70 °C (i.e. 343 K)

Now first note down the millivoltmeter reading at room temperature (25 °C) in the worksheet. Then for other temperature values. Don’t forget to run again after noting down the readings.

Worksheet

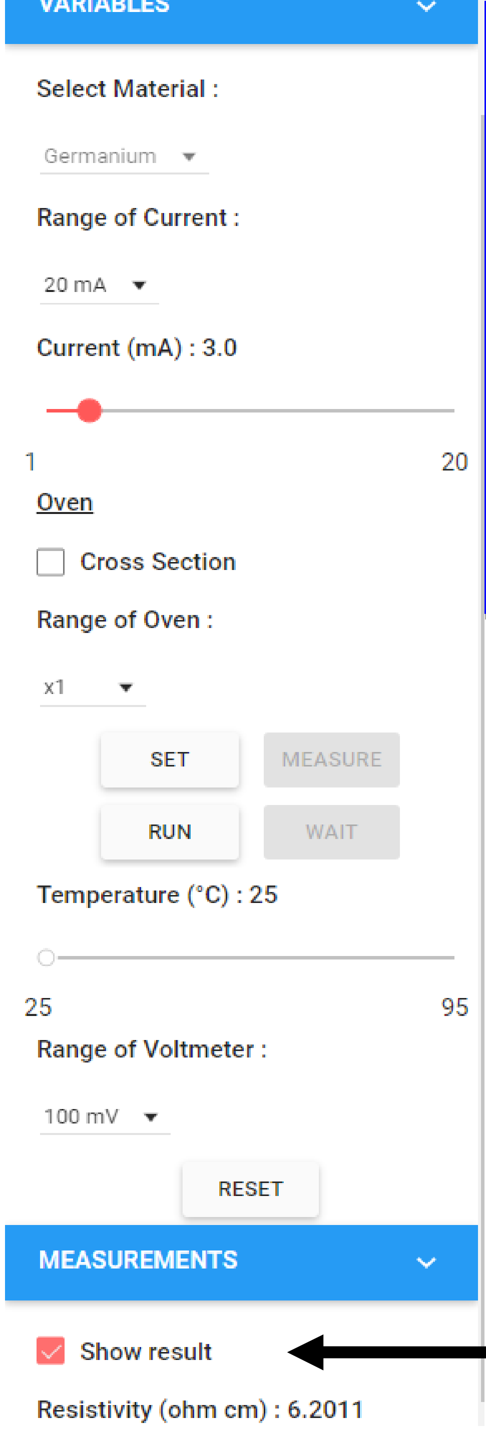
Current I= ……mA

Correction factor, F(W/S) = ….**5.89**..

$\rho = \rho_0/F(W/S) =$ …………….

Temperature (°C)	Temperature (K)	Voltage across inner probe (mV)	1000/T		Considering the correction factor (ρ) unit	logρ

N.B: Take care about the unit.



Resistivity can be calculated by using the equation given below.
Here we take,
Distance between the probes, S as0.2cm and
Thickness of the sample,w as 0.05cm.
From standard table f(w/S) = 5.89

$$\rho = \frac{\rho_0}{f\left(\frac{w}{s}\right)} \quad = \quad \text{.....................} \text{ Ohm cm}$$

$$\rho_0 = \frac{V}{I} \times 2\pi S \quad = \quad \text{.....................} \text{ Ohm cm}$$

Correction factor, F(W/S) = ...**5.89**..
$\rho = \rho_0/F(W/S) =$ ....

Temperature (°C)	Temperature (K)	Voltage across inner probe (mV)	1000/T	Considering the correction factor (ρ)	logρ

Note by clicking this check box the student can find the resistivity value at any particular temperature. This is after considering the correction factor.

Sample Data taken from the virtual lab

Table 1 (temperature range 25 to 70 C) **Current I set at 3 mA**

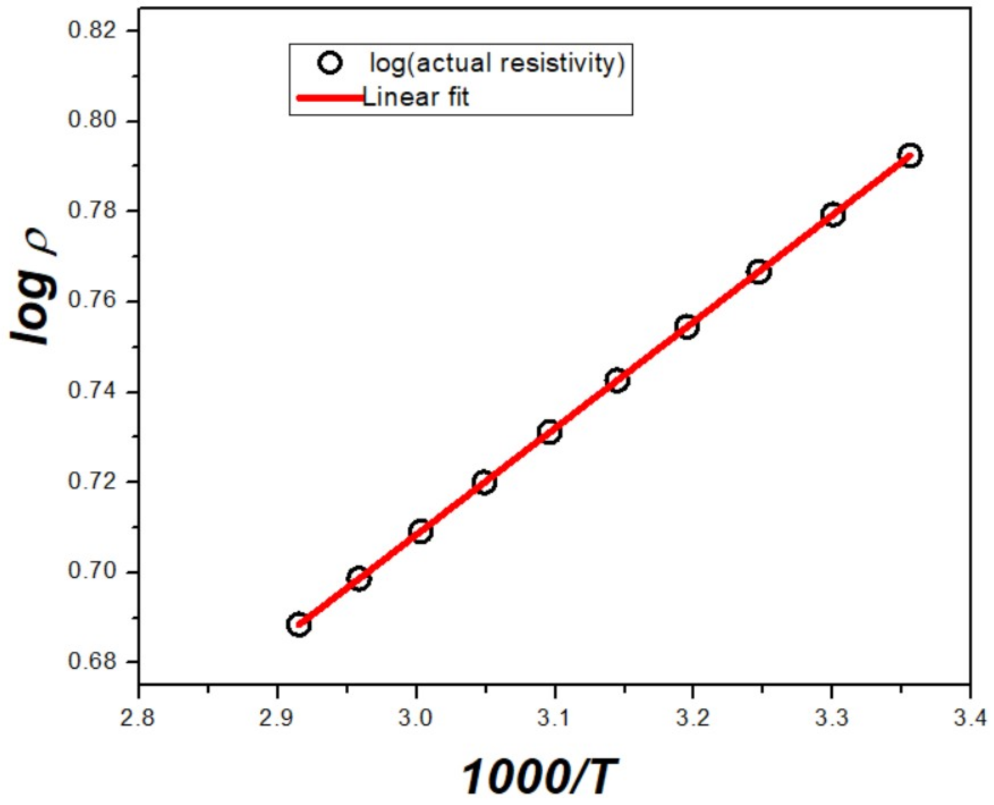
A(X1)	G1(Y1)	B(Y1)	C(X2)	D(Y2)	E(Y2)	F(Y2)
Temperature (C)	Temperature (K)	Voltage accross inner probe (mV)	1000/T	Resistivity (without correction factor)	Actual Resistivity (considering the correction factor)	log(actual resistivity)
25	298	87.24	3.3557	36.52448	6.2011	0.79247
30	303	84.65	3.30033	35.44013	6.017	0.77938
35	308	82.22	3.24675	34.42277	5.84427	0.76673
40	313	79.94	3.19489	33.46821	5.68221	0.75452
45	318	77.78	3.14465	32.56389	5.52867	0.74262
50	323	75.75	3.09598	31.714	5.38438	0.73114
55	328	73.83	3.04878	30.91016	5.2479	0.71999
60	333	72.01	3.003	30.14819	5.11854	0.70915
65	338	70.3	2.95858	29.43227	4.99699	0.69871
70	343	68.67	2.91545	28.74984	4.88113	0.68852

Table 2 **Table 1 (temperature range 25 to 200 C) over range set as x10**

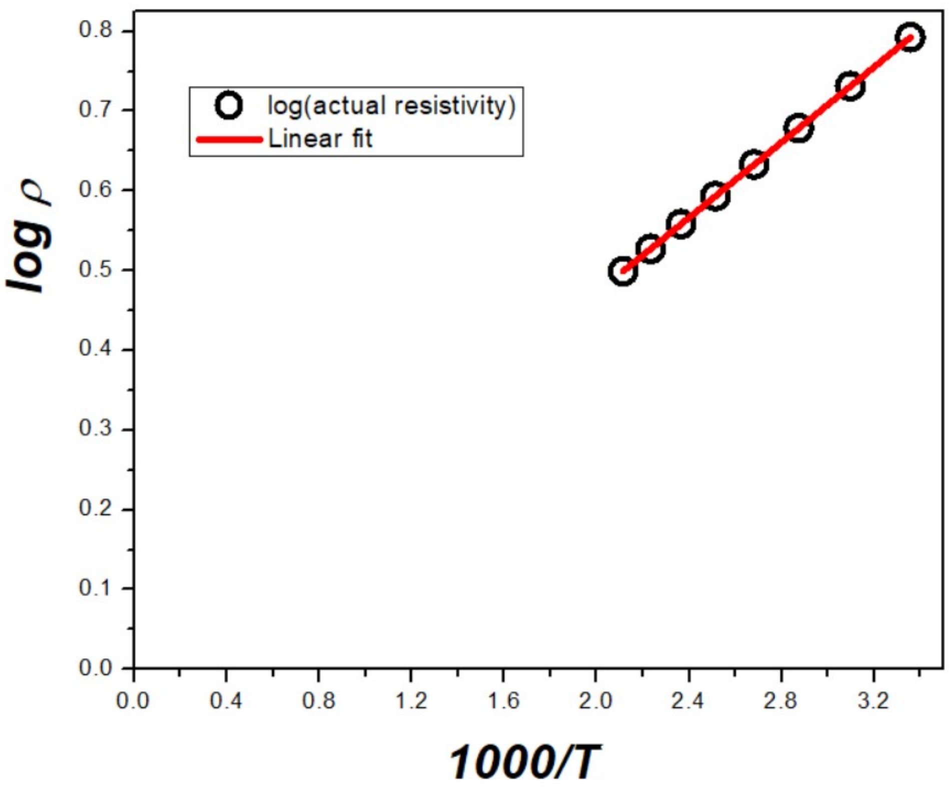
Temperature (C)	Temperature (K)	Voltage accross inner probe (mV)	1000/T	Resistivity (without correction factor)	Actual Resistivity (considering the correction factor)	log(actual resistivity)
25	298	87.24	3.3557	36.52448	6.2011	0.79247
50	323	75.75	3.09598	31.714	5.38438	0.73114
75	348	67.12	2.87356	28.10091	4.77095	0.67861
100	373	60.45	2.68097	25.3084	4.29684	0.63315
125	398	55.16	2.51256	23.09365	3.92082	0.59338
150	423	50.8[illegible]	2.36407	21.30176	3.6166	0.5583
175	448	47.[illegible]6	2.23214	19.82805	3.36639	0.52716
200	473	44.41	2.11416	18.59299	3.1567	0.49923

Plot the graph between 1000/T and log ρ.

*The students can plot the graph in normal graph paper (or in MS-Excel or any graph plotting software)



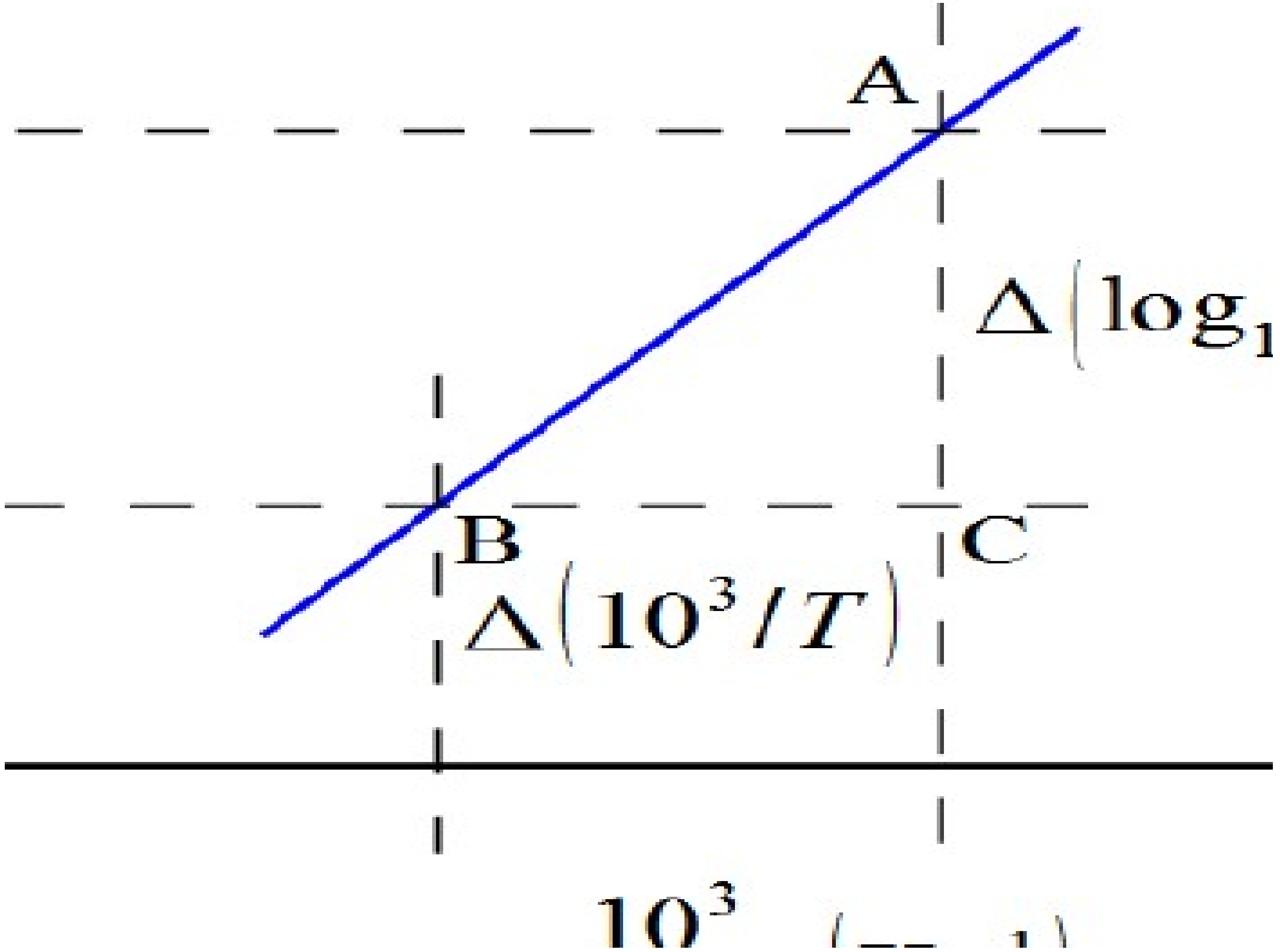
From table 1 (zoomed)



From table 2

How to calculate energy Band gap from the plotted graph?

Plot the graph between 1000/T (along x-axis) and $\log_{10}\rho$ (along y-axis). Find the slope and then use thee following formula



Activity based question

A

A1.1. In this four probe experiment, a Germanium crystal is kept inside the oven. What is the voltage drop at 25 °C when current 1μA is passing through outer two probes on the sample

(A) 29.08 V

(B) 29.08 mV

(C) The outer two probes are not for passing current

(D) Can not be determined with this set up

Activity based question

A

A1.2 : In order to run the oven and take readings from the voltmeter display panel which of the following is the correct order -

(A) Set temperature > Set the range of the voltmeter> wait > Measure

(B) Set temperature > Set the range of the voltmeter > Run > wait > Run (again)

(C) Set the range of the voltmeter > Run > wait> Set temperature

(D) No need to it manually, data will be automatically collected

Activity based question

A

A1.3 : The maximum range of the voltmeter that can be set up in this virtual lab set up is

(A) 1 mV
(B) 100 mV
(C) 10 V
(D) 100 V

Activity based question

A

A1.4 : In this experiment, lets consider the case when 3 mA of current is passing through the Ge crystal at 25 °C. The resistivity of the sample (as shown by the simulator) is –

(A) 87.24 ohm cm
(B) 87.24 ohm^{-1} cm^{-1}
(C) 6.2011 ohm cm
(D) 6.2011 ohm^{-1} cm^{-1}

Activity based question

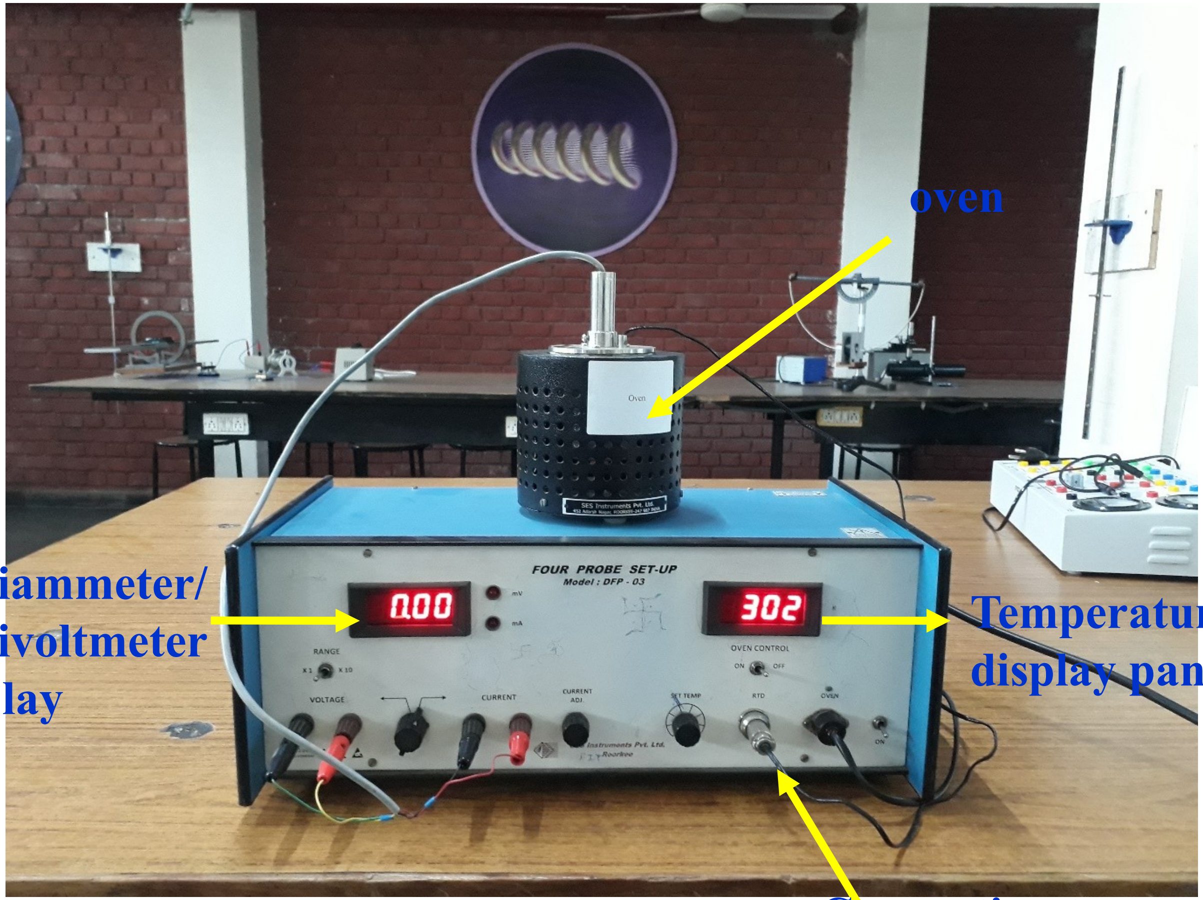
A

A1.5 : In the Four probe experiment, when the temperature of the Ge crystal is increased from 55 °C to 65 °C the change in resistivity (for I = 3 mA) is

(A) 0.2512 ohm cm
(B) 5.2749 ohm cm
(C) 5.0204 ohm cm
(D) None of the above

Experimental set up in our lab

Apparatus: **Probe arrangement, Four probes set up with digital millivoltmeter and constant current generator, Sample crystal (Germanium), Oven**



milliammeter/
millivoltmeter
display

Temperature
display panel

Connection to
temperature sensor

Voltage leads Current leads