Indira Gandhi Delhi Technical University for Women
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Kashmere Gate, Delhi-110006
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DEPARTMENT OF APPLIED SCIENCES & HUMANITIES

Laboratory Manual

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Experiment

AIM:- Determination of Planck's constant using Photo Vacuum Tube

Quantum Theory:

Quantum theory evolved as a new branch of theoretical physics during the first few decades of the 20th century in an endeavor to understand the fundamental properties of matter. It began with the study of the interactions of matter and radiation. Certain radiation effects could neither be explained by classical mechanics, nor by the theory of electromagnetism. In particular, physicists were puzzled by the nature of light. Peculiar lines in the spectrum of sunlight had been discovered earlier by Joseph Von Fraunhofer (1787-1826). These spectral lines were then systematically cataloged for various substances, yet nobody could explain why the spectral lines are there and why they would differ for each substance. It took about one hundred years, until a plausible explanation was supplied by quantum theory.

In contrast to Einstein's Relativity, which is about the largest things in the universe, quantum theory deals with the tiniest things we know, the particles that atoms are made of, which we call "subatomic" particles. In contrast to relativity, quantum theory was not the work of one individual, but the collaborative effort of some of the most brilliant physicists of the 20th century, among them Niels Bohr, Erwin Schrödinger, Wolfgang Pauli, and Max Born. Two names clearly stand out: Max Planck (1858-1947) and Werner Heisenberg (1901-1976). Planck is recognized as the originator of the quantum theory, while Heisenberg formulated one of the most eminent laws of quantum theory, the Uncertainty Principle, which is occasionally also referred to as the principle of indeterminacy.

Around 1900, Max Planck from the University of Kiel concerned himself with observations of the radiation of heated materials. He attempted to draw conclusions from the radiation to the radiating atom. On basis of empirical data, he developed a new formula which later showed remarkable agreement with accurate measurements of the spectrum of heat radiation. The result of this formula was so that 'energy is always emitted or absorbed in discrete units, which he called quanta'. Planck developed his quantum theory further and derived a universal constant, which came to be known as Planck's constant. The resulting law states that the energy of each quantum is equal to the frequency of the radiation multiplied by the universal constant: $E = f \times h$, where f is frequency of the emitted photons and h is called as Planck's constant ($\sim 6.63 \times 10^{-34}$ Js). The discovery of quanta revolutionized physics, because it contradicted conventional ideas about the nature of radiation and energy.

Heisenberg uncertainty principle:

An odd aspect of Quantum mechanics is contained in the Heisenberg Uncertainty Principle (HUP). The HUP can be stated in different ways, first we talk in terms of momentum and position. If there is a particle, such as an electron, moving through space, I can characterize its motion by telling you where it is (its position) and what its velocity is (more precisely, its momentum).

Classically, that is, in our macroscopic world, I could, in principle, measure the position and momentum of the object to infinite precision (more or less). There is really no question about a particle's position and momentum.

In the Quantum mechanical world, the idea that we can locate objects exactly breaks down. Suppose a particle has momentum p and position x. In a Quantum mechanical world, I would not be able to measure p and x precisely. There would be an uncertainty associated with each measurement that I could never get rid of, even in a perfect experiment. The size of the uncertainties is not independent; they are related as

$$\Delta p \, \Delta x \geq \frac{1}{2} \hbar$$

Where the symbol on the right hand side of the inequality, the h with a slash through, it is known as "h bar" and represents the Planck constant h divided 2 Π. The above is a statement of the Heisenberg Uncertainty Principle. A consequence of the Uncertainty Principle is that if an object's position x is defined precisely then the momentum of the object will be only weakly constrained, and vice versa. One cannot simultaneously find both the position and momentum of an object to arbitrary accuracy.

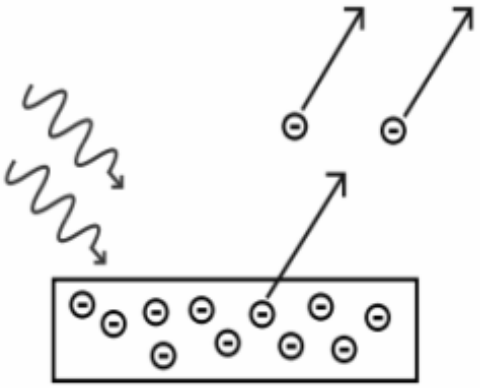
This uncertainty leads to some strange effects. For example, in a quantum mechanical world, we cannot predict where a particle will be with 100 % certainty. We can only speak in terms of probabilities. For example, we can only say that an atom will be at some location with a 99 % probability, and that there will be a 1 % probability it will be somewhere else (in fact, there will be a small but finite probability that it can even be found across the Universe). This is strange.

We do not know if this indeterminism is actually the way the Universe works, because the theory of Quantum mechanics is probably incomplete. That is, we do not know if the Universe actually behaves in a probabilistic manner (there are many possible paths a particle can follow and the observed path is chosen probabilistically) or if the Universe is deterministic in the sense that we could predict the path a particle will follow with 100 % certainty.

A consequence of the quantum mechanical nature of the world is that particles can appear in places where they have no right to be. This has interesting consequences for nuclear fusion in stars.

Photoelectric Effect:

The photoelectric effect is a quantum electronic phenomenon in which electrons are emitted from matter after the absorption of energy from electromagnetic radiation such as X-rays or visible light. The emitted electrons can be referred to as photoelectrons in this context. The effect is also termed the Hertz Effect, due to its discovery by Heinrich Rudolf Hertz, although the term has generally fallen out of use. Study of the photoelectric effect led to important steps in understanding the quantum nature of light and electrons and influenced the formation of the concept of wave– particle duality. The term may also refer to the photo conductive effect (also known as photo conductivity or photo resistivity), the photo voltaic effect, or the photo electrochemical effect.



The photons of the light beam have a characteristic energy determined by the frequency of the light. In the photo emission process, if an electron absorbs the energy of one photon and has more energy than the work function, it is ejected from the material. If the photon energy is too low, the electron is unable to escape the surface of the material. Increasing the intensity of the light beam does not change the energy of the constituent photons, only the number of photons. Thus the energy of the emitted electrons does not depend on the intensity of the incoming light, but only on the energy of the individual photons. Electrons can absorb energy from photons when irradiated, but they follow an "all or nothing" principle. All of the energy from one photon must be absorbed and used to liberate one electron from atomic binding, or the energy is re-emitted. If the photon energy is absorbed, some of the energy liberates the electron from the atom, and the rest contributes to the electron's kinetic energy as a free particle.

Laws of photoelectric emission:

1. For a given metal and frequency of incident radiation, the rate at which photoelectrons are ejected is directly proportional to the intensity of the incident light.
2. For a given metal, there exists a certain minimum frequency of incident radiation below which no photoelectrons can be emitted. This frequency is called the threshold frequency.
3. Above the threshold frequency, the maximum kinetic energy of the emitted photo electron is independent of the intensity of the incident light but depends on the frequency of the incident light.
4. The time lag between the incidence of radiation and the emission of a photo electron is very small, less than 10^{-9} seconds.

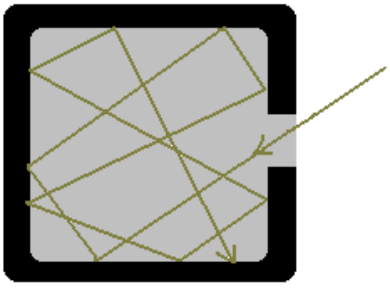
Black body radiation:

All objects absorb and emit electromagnetic radiation. The intensity of the radiation absorbed or emitted by an object may vary for different frequencies and directions of propagation and may be dependent upon characteristics such as the temperature, shape, and material composition of the body.

A blackbody is a special type of object characterized by being a perfect absorber of radiation. From Kirchhoff's law, a blackbody is not only the most efficient radiation absorber; it is also the most efficient radiation emitter. One characteristic of all blackbodies is that the spectrum of radiation they emit depends only upon their temperature. Radiation incident over black bodies will be totally absorbed. Lamp black is the nearest approach to such a body. Apparently, it neither reflects nor transmits the light which falls on it, absorbs all, and hence appears black. But the perfectly black body does not exist in nature, for even the lamp black is found to transmit light of long wavelength. It absorbs about 96% of visible light; platinum black absorbs about 98%.

A black body is an ideal body which allows the whole of the incident radiation to pass into it (without reflecting the energy) and absorbs within itself the whole incident radiation (without passing on the energy). This property is valid for radiation corresponding to all wavelengths and to all angles of incidence. Therefore the black body is an ideal absorber of incident radiation. Black body does not depend on the type of object emitting it. Entire spectrum of black body depends on only one parameter, the temperature, T.

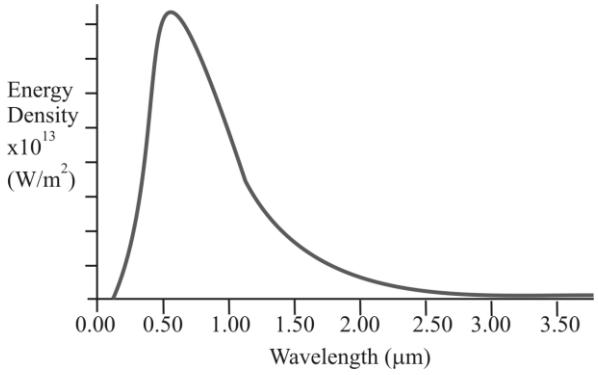
A black body is a theoretical object that absorbs 100% of the radiation that hits it. Therefore it reflects no radiation and appears perfectly black.



In practice no material has been found to absorb all incoming radiation, but carbon in its graphite form absorbs all but about 3%. It is also a perfect emitter of radiation. At a particular temperature the black body would emit the maximum amount of energy possible for that temperature. This value is known as the black body radiation. It would emit at every wavelength of light as it must be able to absorb every wavelength to be sure of absorbing all incoming radiation. The maximum wavelength emitted by a black body radiator is infinite. It also emits a definite amount of energy at each wavelength for a particular temperature, so standard black body radiation curves can be drawn for each temperature, showing the energy radiated at each wavelength. All objects emit radiation above absolute zero. A simple example of a black body radiator is the furnace. If there is a small hole in the door of the furnace heat energy can enter from the outside. Inside the furnace this is absorbed by the inside walls. The walls are very hot and are also emitting thermal radiation. This may be absorbed by another part of the furnace wall or it may escape through the whole in the door. This radiation that escapes may contain any wavelength. The furnace is in equilibrium as when it absorbs some radiation it emits some to make up for this and eventually a small amount of this emitted radiation

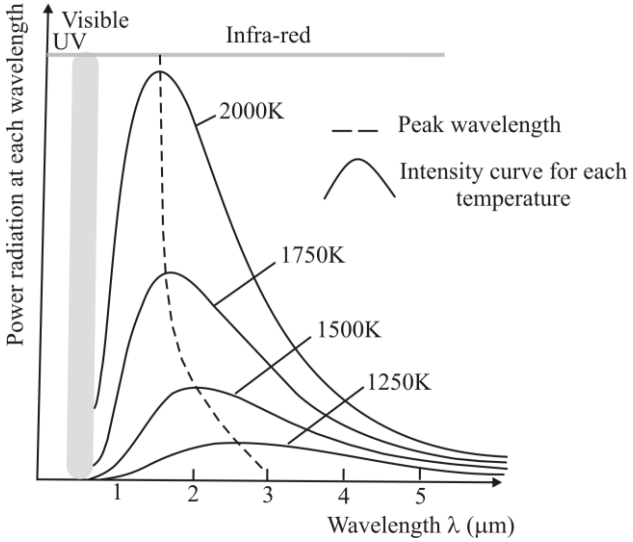
may escape to compensate for the radiation that entered through the hole. Stars are also approximate black body radiators. Most of the light directed at a star is absorbed. It is therefore capable of absorbing all wavelengths of electromagnetic radiation, so is also capable of emitting all wavelengths of electromagnetic radiation. Most approximate blackbodies are solids but stars are an exception because the gas particles in them are so dense they are capable of absorbing the majority of the radiant energy.

Black body radiation curves:



Theoretical black body curve for 5000K

The black body radiation curve (Figure 3) shows that the black body does radiate energy at every wavelength. The curve gets infinitely close to the X-axis but never touches it. The curve touches at infinite wavelength. It also shows that the black body emits at a peak wavelength, at which most of the radiant energy is emitted. At 5000K the peak wavelength is about $5x10^{-7}$m (500nm) which is in the visible light region, in the yellow-green section. At each temperature the black body emits a standard amount of energy. This is represented by the area under the curve.



Black body radiation curves showing peak wavelengths at various temperatures

This graph shows how the black body radiation curves change at various temperatures. These all have their peak wavelengths in the infra-red part of the spectrum as they are at a lower temperature than the previous graph. The graph shows: As the temperature increases, the peak wavelength emitted by the black body decreases. It therefore begins to move from the infra-red towards the visible part of the spectrum. Again, none of the graphs touch the x-axis so they emit at every wavelength. This means that some visible radiation is emitted even at these lower temperatures and at any temperature above absolute zero, a black body will emit some visible light. The graph also shows: As temperature increases, the total energy emitted increases, because the total area under the curve increases. It also shows that the relationship is not linear as the area does not increase in even steps. The rate of increase of area and therefore energy increases as temperature increases.

Planck's constant :

Planck's constant is the fundamental constant in modern physics. It relates the energy of a photon to its frequency. To determine this constant we use Light Emitting Diodes (LED). Diodes today come in a variety of colors. Each color is achieved by having a slightly different semiconductor material. This experiment has being carried out in many manners with a variety of recipes. We chose to do the experiment using a number of LEDs, with different colors including Blue, Green, Red and Orange.

The experiment is based on the fact that the energy of the photon relates to its frequency as:

$$E = h \times f$$

where, E is the energy of photon, h is the Planck's constant and f is the frequency of the emitted photons. When the diode first emits light the voltage across the diode, V_0, is just enough to give energy to electrons to jump between two energy levels. Therefore

$$V_0.e = h \times f$$

where e is the electron charge and V_0 is the threshold voltage. Therefore, by measuring the voltage across the diode when the first light is observed for a number of diodes.

In this experiment, you will use light emitting diodes (LED's) to measure Planck's constant. You should be familiar with semiconductors and diodes from Moderns Physics. To review: LED's are semiconductor that emit electromagnetic radiation in optical and near optical frequencies when a voltage is applied to them. LED's emit light only when the voltage is forward bias and above a minimum threshold value. This combination of conditions creates and electron hole pair is diode. Electron hole pairs are charge carries and move when placed in and electrical potential. Thus many electron hole pairs produce a current when placed in an electric field. Above the threshold value the current increases exponentially with voltage.

A quanta of energy is required to create an electron hole pair and this energy is released and electron and a hole recombine. In most diodes this energy is absorbed by the semiconductor as heat, but in LED's this quanta of energy produces a photon of discreet energy E = hf**.** Because multiple states may be excited by increasing the voltage across

a diode, photons of increasing energies will be emitted with increasing voltage. Thus the light emitted by an LED may span a range of discrete wavelengths that decrease with increasing voltage above the threshold voltage (shorter wavelength = higher energy). We are interested in the minimum wavelength that is determined by the minimum energy needed to just to create an electron hole pair. It is numerically equal to the turn on voltage of the LED. The relation between the maximum wavelength, λ, and the turn on voltage, V_0, is

$E = hf = hc/\lambda$.....(1)

$E = eV_0$.....(2)

From (1) and (2) we get,

$hc/\lambda = eV_0$

or $h = eV_0\lambda/c$.....(3)

Where,

h is Planck's constant,

e is the electronic charge,

V_0 is Threshold voltage,

λ is wavelength of LED and

c is the velocity of light

The maximum wavelength of the LED can be measured to a resolution of a few nanometers with a good spectrometer. If the turn on voltage V_0, is measured for several diodes of different color (and different maximum wavelength λ), a graph of V_0 Vs 1/ λ should be linear a slope of hc/e. An experimental value of the speed of light c,
and the charge of electron, and computing h.

Usages of Planck's constant:

The Planck constant is used to describe quantization. For instance, the energy (*E*) carried by a beam of light with constant frequency (*v*) can only take on the values

$$E = nhv,\ n \in N$$

It is sometimes more convenient to use the angular frequency $\omega = 2\pi v$, which gives

$$E = nhw,\ n \in N$$

Many such "quantization conditions" exist. A particularly interesting condition governs the quantization of angular momentum. Let J be the total angular momentum of a system with rotational invariance, and J_z the angular momentum measured along any given direction. These quantities can only take on the values

$$J^2 = j(j+1)h^2,\ j = 0,1/2,1,3/2,.....,$$

$$J_z = mh, \qquad m = -j, -j+1,.....,j.$$

Thus, ħ may be said to be the "quantum of angular momentum".

The Planck constant also occurs in statements of Heisenberg's uncertainty principle. Given a large number of particles prepared in the same state, the uncertainty in their position, Δx, and the uncertainty in their momentum (in the same direction), Δp, obey

$$\Delta x \, \Delta p \geq \frac{1}{2} h$$

Where the uncertainty is given as the standard deviation of the measured value from its expected value. There are a number of other such pairs of physically measurable values which obey a similar rule.

Dirac constant:

The Dirac constant or the "*reduced* Planck constant", $h = h/2\pi$, differs only from the Planck constant by a factor of 2π. The Planck constant is stated in SI units of measurement, joules per hertz, or joules per (cycle per second), while the Dirac constant is the same value stated in joules per (radian per second).

In essence, the Dirac constant is a conversion factor between phase (in radians) and action (in joule-seconds) as seen in the Schrödinger equation. The Planck constant is similarly a conversion factor between phase (in cycles) and action. All other uses of Planck's constant and Dirac's constant follow from that relationship

Significance of the size of Planck's constant

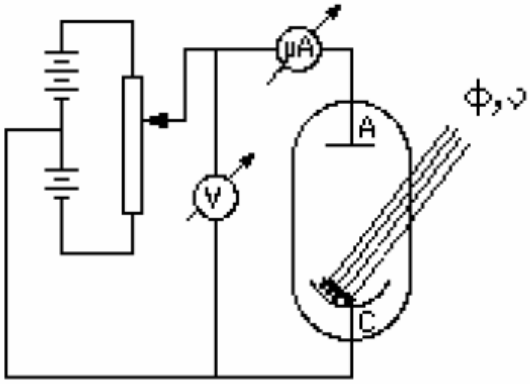
Expressed in the SI units of joule seconds (J·s), the Planck constant is one of the smallest constants used in physics. The significance of this is that it reflects the extremely small scales at which quantum mechanical effects are observed, and hence why we are not familiar with quantum physics in our everyday lives in the way that we are with classical physics. Indeed, classical physics can essentially be defined as the limit of quantum mechanics as the Planck constant tends to zero.

In natural units, the Dirac constant is taken as 1 (i.e., the Planck constant is 2π), as is convenient for describing physics at the atomic scale dominated by quantum effects.

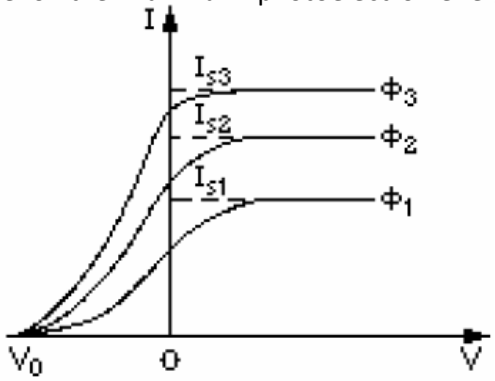
There are several kinds of photoelectric effects:

1. The photoionisation (the photoelectric effect on isolated atoms) – which consists of the extraction of electrons from the atoms of a gas at their interaction with visible or ultraviolet radiation.
2. The photoelectric effect of X-rays – which is given by the extraction of the interior electrons of atoms by the X-rays (that have energies of the order of thousands electron volts).
3. The internal photoelectric effect – which represents the increase of the number of "free" electrons of a metal or a semiconductor without leaving the solid, because of the interaction between the atoms and the light waves. One will obtain a decrease of the irradiated material electrical resistance.
4. The external photoelectric effect – which represents the emission of electrons by a condensed substance under the action of radiation from the visible and ultraviolet spectrum.
5. The photovoltaic effect – which consists of the appearance of an electromotor bias at the contacts between a semiconductor and a metal or between two semiconductors, if the contact region is irradiated with a light beam.

This work studies the external photoelectric effect for a metal (the cathode of a photoelectric cell). Voltage V (positive or negative with respect to the cathode); a voltmeter to measure this voltage; a microammeter to measure the photoelectric current I. The current – voltage characteristics for constant frequency and variable flow The laws of the external photoelectric effect were experimentally obtained by Lenard in 1905 and the experimental method was described by Millikan in 1916.



A simple circuit is used (see Figure 1). It is formed by: a photoelectric cell, whose cathode C is irradiated with a light beam characterized by the frequency ν and the flow ϕ; a potentiometer allowing to apply on the cell anode A a (ϕ1 < ϕ2 < ϕ3) are presented in Figure 2. From these characteristics one can determine the saturation current Is and the braking voltage V_0. The last one stands for canceling the photoelectric current intensity and it is a measure of the maximum photoelectron energy.



Maintaining constant the flow Φ and changing the frequency ν of the incident light, one can observe the following:

- The photoelectric effect is not produced for a frequency lower than a threshold frequency ν*t* , depending on the cathode material.
- The modulus of the braking voltage increases linearly with the frequency (Fig. 3).

On this basis, we can infer the following laws for the external photoelectric effect:

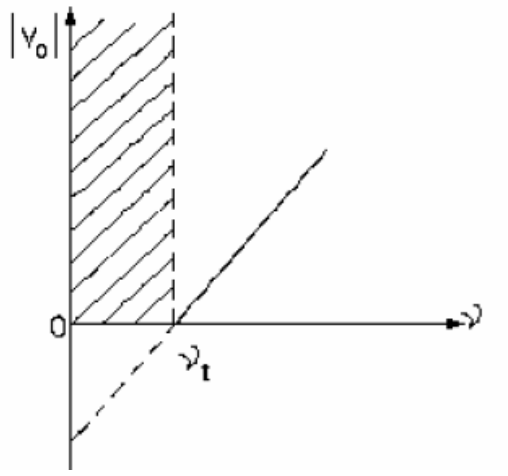
1. The saturation intensity of the photoelectric current is directly proportional with the flow of the incident radiation at a constant frequency *Is* ~ ϕ.

2. The maximum photoelectron kinetic energy increases linearly with the radiation

frequency and does not depend on their flow (E_k max = av + b). The slope of this line does not depend on the experimental conditions (a is an universal constant).

3. The external photoelectric effect is produced only if the incident radiation frequency is greater than or equal with a minimum value, called threshold frequency ν_t , specific for each material.

4. The external photoelectric effect is practically instantaneous.



These laws appear to be in total contradiction with the electromagnetic wave theory of the light, but they become obvious in the frame of the corpuscular theory of light. Their theoretical explanation was given by Einstein in 1905.

This theory considers the light as a flow of photons having the energy $h\nu$ and effect corresponds to the energy transfer from a photon to an electron, in other words represents a plastic collision between the photon and the electron, with photon annihilation. If the energy of the photon hν is greater than the extraction work, the emitted electron leaves the substance with a kinetic energy E_k ,the momentum h /λ (h is Planck's constant, ν represents the frequency and λ is the light wavelength.). Using this fact, Einstein showed that the photoelectric The energy conservation theorem applied to this effect leads to the following formula:

$$h\nu = W_e + E_k , \qquad (1)$$

where We is the extraction work (the energy needed for the electron to leave the substance). The equation (1) is called Einstein's equation. In the 81 case of the threshold frequency, the electron kinetic energy is zero and we have:

$$h\nu_t = W_e . \qquad (2)$$

The determination of the kinetic energy E_k for the emitted electrons is made by using the braking electric field method: on the photoelectric cell anode is applied a negative bias with respect to the cathode. This leads to the braking of the electrons and the decrease of the photoelectric current braking voltage V_0 is experimentally determined for different frequencies intensity I. The maximum value of the modulus of this bias is called braking voltage and is quoted V_0. It corresponds to the case when no electron reaches the anode

and I becomes zero. Then

$$E_k = \frac{mv^2}{2} = e|V_0|,$$

Where *e* is the elementary charge.
From the equations (1 – 3) we obtain: And

$$h\nu = h\nu_t + e|V_0|$$

therefore:

$$|V_0| = \frac{h}{e}\nu - \frac{h}{e}\nu_t .$$

The last formula explains the second and the third laws of the external photoelectric effect and the experimental results shown in Figure 3. The, straight line corresponding to the equation $|V_0| = f(\nu)$ is drawn and from its slope the Planck's constant is computed.

Glass Blowing for Vacuum Devices

Magnesium Photoelectric Cell

When electromagnetic radiation falls on a metal surface, electrons can be released. Electron emission only occurs if the frequency of the radiation is above a value called the threshold frequency. The threshold frequency is dependent upon the type of material.

Wave theory does not explain the photoelectric effect. Instead, it is necessary to consider the radiation as particles called photons. The energy of each photon is related to the frequency by E = hf where E is the energy in joules (J), h is Planck's constant (6.626×10^{-34}Js) and f is the frequency in Hz. Joules can be converted to electron volts by dividing by 1.6x10-19.

Each metallic element has a fixed value called its work function, which is usually expressed in electron volts (eV). If photons striking the material have energies greater than its work function, electrons will be released. This means that the lower the work function a material has, the lower the frequency and hence the longer the wavelength of electromagnetic radiation that will cause electron emission. Some elements such as caesium (1.95eV) and sodium (2.36eV) exhibit photoelectric emission with visible light, but the threshold of most metals is in the ultraviolet.

A photoelectric cell consists of a very clean surface of a low work function material in a vacuum. One connection is made to this surface, which is called the photocathode. A second electrode (the anode) is positioned in front of the photocathode. A voltage is applied from anode to cathode, so that electrons which are emitted are electrostatically attracted to the anode. The resulting current is then measured and is proportional to the intensity as long as the wavelength of the light is constant.

The first tried making a photoelectric cell using sodium obtained from a failed low pressure sodium lamp. It coiled tungsten wire around the sodium so that it could be evaporated. The problem was that sodium is so reactive that by the time It had

assembled the bulb and fitted it to the pump, it had all converted to sodium hydroxide due to moisture in the air. The lowest work function metals are mostly in the left hand column of the periodic table and are therefore very reactive making them difficult and dangerous to handle.

Magnesium has a work function of about 3.66eV which is less than most metals. For photoelectric emission to occur, the photons would require energies of 3.66 x 1.6×10^{-19} = 5.86×10^{-19}J. The threshold frequency is therefore 5.86×10^{-19} / 6.626×10^{-34} =8.84×10^{14}Hz. The threshold wavelength is therefore $\lambda = c/f = 3 \times 10^{8} / 8.84 \times 10^{14}$ = 339nm. This is just beyond violet, in the soft ultraviolet part of the spectrum.



I used a construction very similar to 'Filament Lamp B'. I did this by pre-beading the pin with glass. I blew out a small area on the side of the bulb using a sharp flame and fused the beaded pin into it. I found that re-heating the entire bulb again with the pin in it until it starts to collapse and then blowing it out again gives a stress free result. This has to be done before the pump tube is attached.



This is the stem, which was made in the same way as that of 'Filament Lamp B'. I spot welded a rectangle of steel sheet to one of the nickel/iron wires using the home-made spot welder. I crimped a thin strip of magnesium between the second lead- in wire and the end of the steel sheet. Passing current through the magnesium in a vacuum will cause it to evaporate on to the inside surface of the bulb and make electrical contact to the valve pin.

This is the completed cell. Getting the stem to fuse to the bulb tube with the magnesium ribbon correctly aligned with the pin was quite difficult.

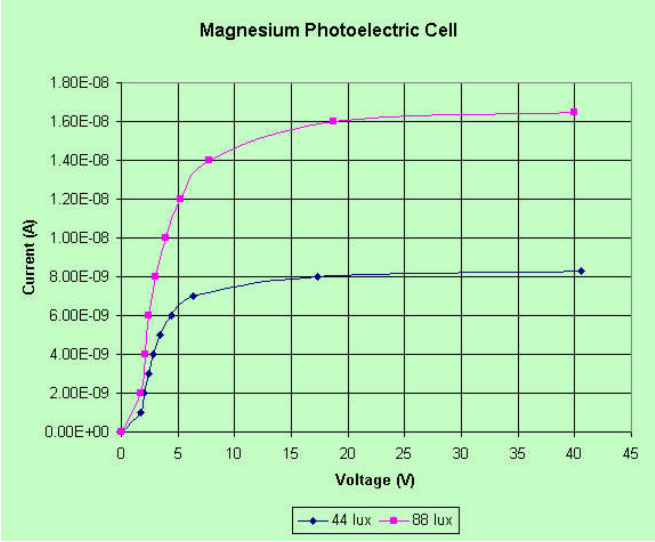
The purpose of the metal plate is to act as a shield so that magnesium does not coat the inside of the bulb opposite the pin. This provides a window for light to enter.



Here, the cell is mounted on the vacuum system and the magnesium has been evaporated. I had trouble getting it to evaporate. I made the magnesium ribbon too wide. As a result, I had to pass such a heavy current that the lead-in wires also started to evaporate. Surprisingly, the glass-metal seals did not fail catastrophically and a working cell was achieved.

The black disc on the left is a light meter. The purple light on the right is an ultraviolet lamp intended for checking bank notes.

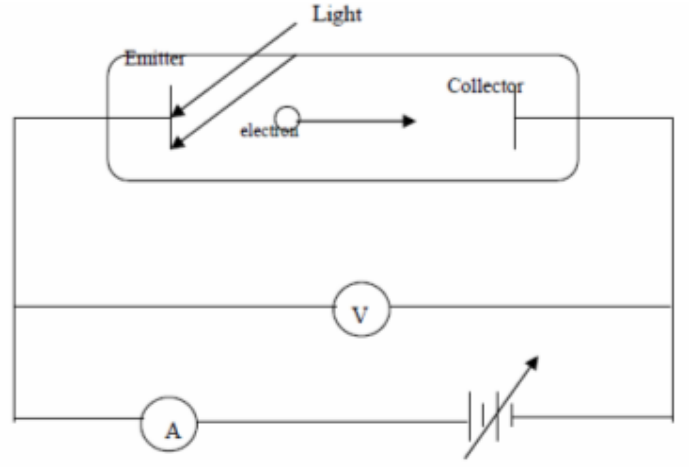
The voltage source was a Weir regulated bench power supply. The current was measured using a Cooknell Electronics CP13 pico-ammeter. The luminous flux was measured using a Diffusion Systems photometer. The photometer was calibrated for a tungsten light source and is therefore unlikely to be accurate for a UV source, but will give meaningful relative measurements. Luminous flux values are given in lux which is lumens per square meter.



The characteristics were measured at an indicated luminous flux of 44 lux and 88 lux. The results are shown in the graph below. As the voltage is increased, the current saturates at around 30V. This corresponds to all of the electrons emitted by the cathode being collected by the anode. The saturated current at 44 lux was 8.3nA and at 88 lux it was 16.5nA. This indicates that the current had very good proportionality to the luminous flux.

The cell had some sensitivity to a tungsten filament lamp. At 76 lux, the saturated current was 9.1pA compared to a dark current of 4.2pA.

The above measurements were taken with the cell still on the pump. After the cell was sealed-off and detached from the pump, the sensitivity decreased dramatically. It is possible that overheating the lead-in wires damaged the glass-metal seals. It is difficult to tell because of metal deposited on the end of the stem.



Schematic of the photoelectric effect apparatus.

A schematic of the photoelectric effect apparatus is shown in figure 1. A light sensitive material, called an emitter is placed in a transparent evacuated tube along with a collector. This device is then connected to a variable voltage source which allows the generation of an adjustable (uniform) electric field between the emitter and the collector. As light is incident on the light sensitive emitter, electrons are released which have an initial kinetic energy. If the electric field does work on the charged particle equal to the charged particle's initial kinetic energy, the charged particle will come to rest. As a result, the electrical current between the emitter and the collector will go to zero.

The kinetic energy of the ejected electrons is determined by the frequency of the light striking the phototube. The quantity of ejected electrons is dependent on the intensity of the light. The maximum kinetic energy, K_{max}, of the photoelectrons is given by

$$K_{max} = hf - \phi$$

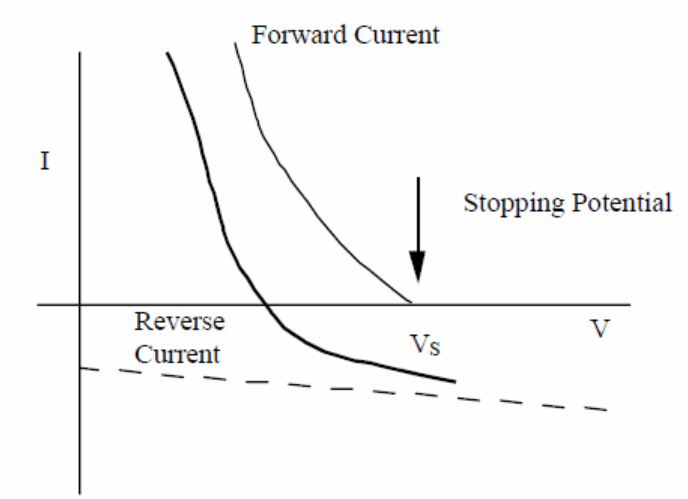
where h is equal to Planck's constant, f is the frequency, and ϕ is the work function.
Since the work function, which is the energy required to release an electron from the surface a metal, is a constant for any given material, the maximum kinetic energy depends directly on the frequency of the incident radiation. If the potential applied to the anode is gradually decreased and made negative, the electrons ejected from the cathode will not have enough energy to reach the anode and will be repelled back to the cathode. At a certain voltage called the "stopping potential", Vs, the electron current from the cathode to the anode will go to zero. At that point, the maximum kinetic energy of the electrons is equal to the stopping potential where

$$\mathbf{eVs = hf - \phi}$$

Where e is equal to the electronic charge (1.6×10^{-19} C), and V_S is the stopping potential (volts). By experimentally determining the stopping potential for several values of frequency and using the above equation, Planck's constant can be experimentally determined and compared with the known value.

Identification of Sopping Voltage:

In order to properly analyze the current-potential curves to obtain the stopping potential, the emission of electrons from the anode must be taken into account. Anode emission probably occurs because of a small amount of photosensitive material deposited on it during construction of the cell. Although the relative number of electrons emitted by the anode is very small, their contribution to the current is appreciable. Thus, the potential required to stop completely the electrons emitted by the cathode is greater than the potential at which the net current is zero. A typical experimental curve is given below (in bold). It can be seen to be composed of two curves: forward current (thin line) and reverse current (dashed line). The forward current is the electron current from cathode to anode, while the reverse current results from anode emission. The stopping potential is estimated as that value of the voltage at which the observed current becomes approximately constant.



In summary, the stopping potential could be a higher voltage than the voltage at which the photocurrent is zero. When the average value of the stopping potential has been obtained for each frequency, stopping potential should be plotted against frequency. Planck's constant can be determined from the slope of the V-f curve by using the relation

$$h = e(\Delta V)/(\Delta f) \text{ (slope of the line)}$$

The work function ϕ can be determined by the second fit parameter, the y-axis intercept at f = 0.

Part II:

A: Wavelength Dependence of the Kinetic Energy of the Liberated Electron

1. Attach the grating to the mercury lamp and set-up the experiment as shown in Figure 2.
2. You can easily see five colors in the mercury light spectrum (see figure 4). Adjust the apparatus so that only one of the colors is incident on the evacuated cell (Note; use green and yellow filters for corresponding colors. Place the filter using the magnets on the white screen entering the evacuated cell).
3. Connect apparatus to Voltmeter, set to Voltage.
4. Push and release the "push to zero" button. Wait until the voltage stabilizes. This value is equivalent to the stopping voltage. Record the value in Table 2.
5. Repeat this for all five colors of light.
6. Create a plot of stopping voltage versus light frequency that will allow. Determine both the work function of the photosenstive material and Planck's constant from the plot. Report your results and calculate the error in your measured value of Planck's constant.

B: "Brightness" Dependence of the Energy of the Liberated Electron

Choose one light color and setup the apparatus so that light is incident on the

evacuated cell. Now place the attenuator at the same location you placed the filter. If you are using yellow or green light, stack the attenuator and filter.

- Measure the stopping voltage at different attenuation levels and fill-in table 3.
- At each attenuation level, discharge the evacuated tube by holding down the "zero" button for 3 minutes.
- Start time when you release the button and end timing when the voltage reaches a stable value. Record these values in table 3 as well.

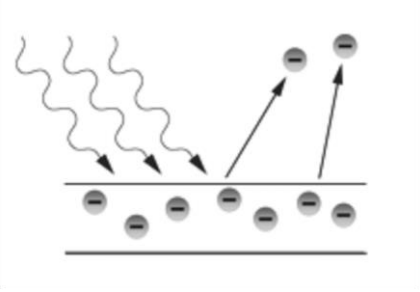
Study of Photoelectric Effect: Determination of Planck's constant.

Photoelectric Effect

The dual nature of light, that light exhibits characteristics of waves and particles at different times is connected to the photoelectric effect. The photoelectric effect is explained considering the light made by photons, so light has characteristic of particles.

The photoelectric effect is the emission of electrons from matter upon the absorption of electromagnetic radiation, such as ultraviolet radiation or X-rays. The photoelectric effect was explained mathematically by Albert Einstein, who extended the work on quanta developed by Max Planck. Einstein established the equation of photoelectric effect, also called the Einstein equation for photoelectric effect. The light is made by photons. Photon (quanta of light) interacts with substances. The absorption of single quanta of light explains the photoelectric effect. The idea of light quanta was motivated by Max Planck's law of black-body radiation. Einstein's explanation of the photoelectric effect won him the Nobel Prize in 1921.

Exposing a metallic surface to electromagnetic radiation, the photons are absorbed and electrons are emitted, and current is produced.



Photoelectric Effect

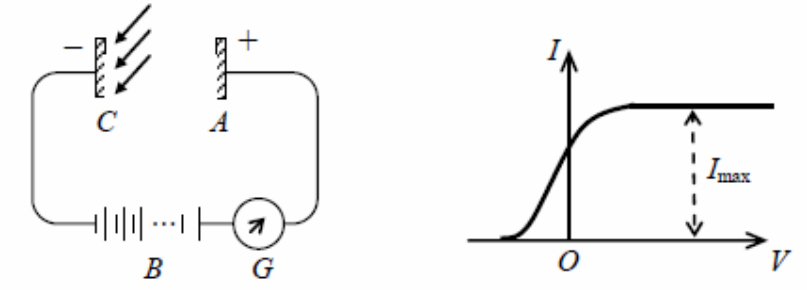
The electromagnetic radiation must have the frequency equal or bigger than the threshold frequency $\nu_{threshold}$. The threshold frequency is specific to the type of surface and material.

No electrons are emitted for radiation with a frequency below that of the threshold, as the electrons are unable to gain sufficient energy to overcome the electrostatic barrier

presented by the termination of the crystalline surface. This electrostatic barrier is the material work function, $L_{function}$ the minimum energy required to remove an electron from atomic binding. Alkaline metals have the smallest values for work function. Some values for the work function are given in the table below.

Metal	Li	Na	K	Rb	Ce
Work Function (*eV*)	2,5	2,1	2	1,5	1,4

Photoelectric cells work in visible, UV or infrared in function of the values of the work function. Some cells (with Na and K) work in UV and others (with alloy of Cs) in infrared. The emitted electrons are called *photoelectrons*. The energy of the photon is absorbed by the electron and, if sufficient, the electron can escape from the material with a finite kinetic energy. A single photon can only eject a single electron, as the energy of one photon may only be absorbed by one electron. The photons of the light beam have a characteristic energy given by the wavelength of the light. In the photoemission process, an electron can be ejected from the material if absorbs the energy of one photon and has more energy than the work function. If the photon energy is too low, however, the electron is unable to escape the surface of the material. Increasing the intensity of the light beam does not change the energy of the constituent photons, only their number. The energy of the emitted electrons does not depend on the intensity of the incoming light.
Photoelectric effect is studied with a photoelectric cell and the variation of photoelectric current intensity with respect voltage is given in the figure below. The photoelectric current intensity increased from zero, has some values and reaches the maximum value $I_{max.}$



Laws of Photoelectric Effect

- The photoelectric current intensity is inversely proportional to the intensity of the light.
- The energy of the photoelectrons increased with increasing frequency of incident light (1905).
- The photoelectric effect occurs only for frequencies equal or bigger than the

threshold frequency threshold. The threshold wavelength is in visible for alkaline metals and in UV for the majority of the other metals. Some examples of threshold wavelength are given in the table below.

Metal	Li	Na	K	Ta	Hg	Au	Fe	Ag
λ_0 (Å)	5000	5400	5500	3050	2735	2650	2610	2610

- The photoelectric effect occurs in a very small time 10^{-8} s.

Einstein's equation for photoelectric effect

Enunciation of Einstein's equation (1905) for photoelectric effect is: the energy of photon is equal to the energy needed to remove an electron plus the kinetic energy of the emitted electron.

Einstein's equation for photoelectric effect was in good concordance with Millikan's experiments (1916).

The mathematical statement is given by:

$$h\nu = L_{\text{function}} + \frac{1}{2}mv^2.$$

$$h\nu = L_{\text{function}} + \frac{1}{2}mv^2.$$

where hv is the energy of photon, the expression of the work function is replaced by eV_0 which is the energy needed to overcome the electrostatic barrier, his Planck's constant, v is the frequency of the incident photon, $\frac{1}{2}mv^2$ is the maximum kinetic energy of ejected electrons, e is the electric charge of electron, m is the mass of the ejected electron, v is the velocity of the ejected electron.

Furthermore, one gets:

$$\frac{1}{2}mv^2 = eV_s.$$

Where Vs is the *sticking voltage* – the value of voltage corresponding to the zero value of the photocurrent. The Einstein equation becomes:

$$h\nu = eV_s + L_{\text{function}}.$$

Einstein explained the equation of photoelectric effect considering that light is made by photons. More quanta generate bigger values for energy. Some effects for UV and X-rays are highlighted by the light characteristic of particles. Einstein's equation for photoelectric effect was studied by Millikan (1916) who won the Nobel Prize in 1923 and after this by Lukirski (1928). The Planck's constant was obtained from studies.

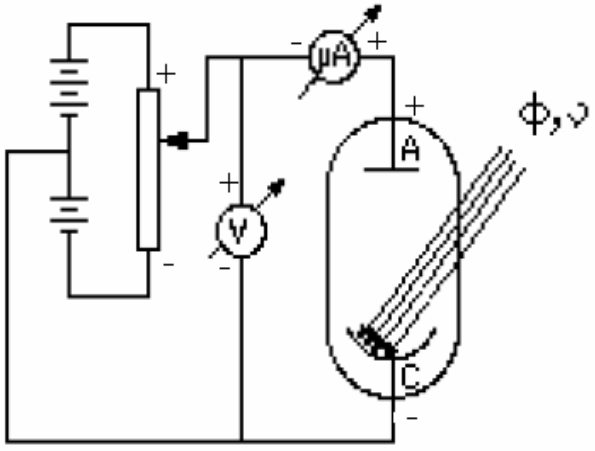
Objective: Determination of Planck's constant using Photo Vacuum Tube.

Equipment Needed:

1. Planck's constant trainer
2. Patch cords
3. Mains cord
4. Filters

Procedure:

1. Take the Planck's constant Setup & fix the photo vacuum tube at particular position.
2. Connect + ive terminal of DC power supply to + ive terminal of DC voltmeter and –ive terminal of DC ammeter.
3. Now connect - ive terminal of DC power supply to - ive terminal of DC voltmeter.
4. Connect + ive terminal of DC ammeter to anode (+ ive terminal) of photo vacuum tube.
5. Connect - ive terminal of DC voltmeter to Cathode (- ive terminal) of photo vacuum tube as shown in figure below.



6. Set the range of DC voltmeter at 200 mV and Ammeter at 2 μA.
7. Connect the mains cord and switch on the power supply and light source.
8. Now you can observe some value of current on ammeter.
9. Now first insert the blue color filter in front of photo vacuum tube.

Note: After inserting filter, if you are not getting current properly then slide the photo vacuum tube towards light source till the getting some current.

10. Switch on the DC power supply.

11. Now vary the DC voltage slowly by variable resistance pot and see the value of current. It will be decreases as the increase of voltage.

12. When the current becomes zero, note the value of applied voltage by DC voltmeter. This is stopping potential for blue color.

13. Now switch off the DC power supply.

14. Again repeat the same procedure for different colors of filters at same distance.

15. Note down all the values in observation table given below.

Color of Filter	**Wavelength λ**	**Stopping potential V_0**

16. Now use the formula given below and put the value of all parameters used in formula and calculate the value of Planck's Constant

$$h = \frac{eV_o}{c}$$

Take mean value of h calculated for different filters. Now w.k.t. e =

1.6×10^{-19} C

$C = 3 \times 10^8$

h =..... Joule Sec.

Filters : Violet, Royal Blue, Tokyo Blue & yellow

Wavelength

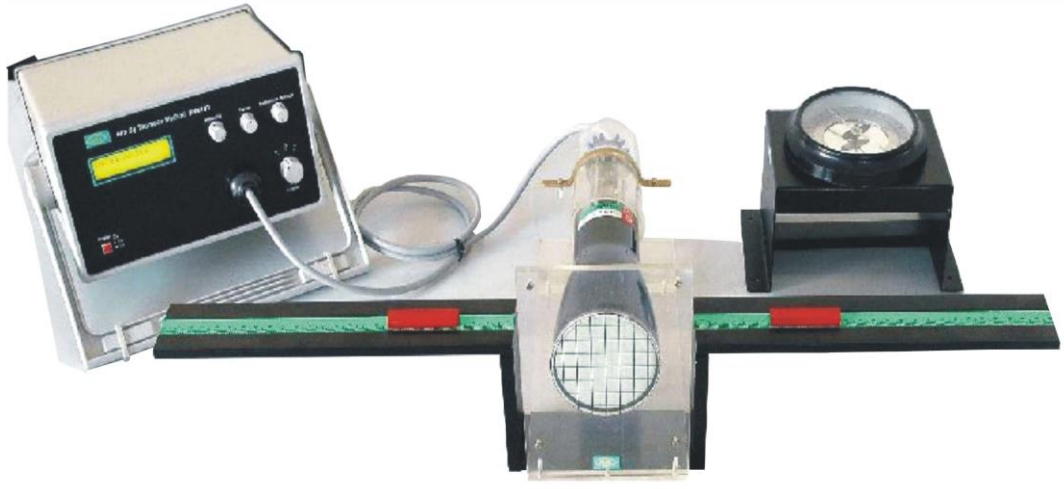
Violet	:	430nm
Royal Blue	:	450nm
Tokyo Blue	:	460nm
Yellow	:	580nm

Experiment

AIM: To determine the value of e/m by J J Thompson method.

e/m By Thomson Method setup is very useful for physics and basic science laboratories. This is used to find the specific charge ratio of an electron particle in a CRT by Thomson method using bar magnet. This system is provided with a Power Supply unit for CRT and Deflection Magnetometer with stand arrangement and mounting stand for CRT. NV6103 have a microcontroller based instrument with LCD display for displaying deflection voltage. It is highly secure and stable system. J.J Thomson was the first scientist who measured charge to mass ratio (e/m) of an electron. When a narrow beam of charged particles are projected at constant speed (v) across a magnetic field in a direction perpendicular to the field, the beam of particles experiences a force, which make them move in a circular path.

It consists of a highly evacuated glass tube, fitted with electrodes. Electrons are produced by heating a tungsten filament electrically. Electrons are made to accelerate and form a beam by passing through the plates. They are passed through electric and magnetic field. Finally they fall on zinc sulphide screen.



Cathode Ray Tube:

Distance between plates (d)	:	1.4 cm
Length of plates (*l*)	:	3.23 cm
Distance between screen and plates (L)	:	14.5 cm

Objective: Determining the value of specific charge e/m of an electron by Thomson method

Equipment Needed: Deflection Magnetometer, Two Bar Magnets, CRT, Stand Arrangement

Theory:

In this method cathode ray tube is used in which cathode emits electrons, anode accelerate them, passes through a small hole, to another anode which concentrate them into a fine beam. Then passes through between two parallel plates, which can deflect the beam in a vertical plane by an electric field E applied between both the plates. The beam of electron can also be deflected in same plane applying a magnetic field B perpendicular to the plane of plates. This narrowed collimated beam of accelerated electrons than strikes the fluorescent screen to produce a glowing spot. Three terms arise as,

1. If an electric field E applied by a potential difference of V volts between plates the electrons experience a force F in a direction perpendicular to the direction of motion of the beam.

$$F_e = E\,e \qquad \ldots 1$$

2. If B be the uniform magnetic field applied in the region P-P in a horizontal direction perpendicular to the direction of electrons beam, the force experienced by electrons is,

$$F_{mag} = B\,e\,v \qquad \ldots 2$$

Where e is the electron charge, v is the velocity of electron and F_{mag} is the magnetic force.

This force F_{mag} acts perpendicular to the direction of B as well as in the original direction of electron motion (in accordance to Fleming's left thumb rule). The speed of electrons remains unchanged, but its path becomes circular providing the amount of centripetal force.

$$Fmag = B\,ev = \frac{mv^2}{r} \qquad \ldots 3$$

Where m is the mass of an electron and r is the radius of circular path.

$$\text{Thus } \frac{e}{m} \propto \frac{v}{Br} \qquad \ldots 4$$

3. If an electric field E applied to deflect the beam in OO' direction, than a magnetic field B is applied to bring beam back to O. It means that the force of electrostatic field is equal and opposite to applied magnetic field, so $F_e = F_{mag}$, and two forces nulled each other to bring beam back to original position.

Thus $$Ee = B\,e\,v \qquad \ldots 5$$

Or $$v = \frac{E}{B} \qquad \ldots.6$$

Substituting values of v from 6 into 4

$$e/m = E/B^2r \qquad \ldots.7$$

Radius 'r':

According to the figure 6, the original electron beam is preceding straight path G, M, O and impressed upon

screen at a point O. In the presence of magnetic field, the beam travels along a circular arc G, D whose radius is r. beyond point D, the beam leave magnetic field and proceeds straight in direction along with the tangent K, DO' (drawn on the circular arc at point D). Drawing GN normal to GKO and MDN normal to KDO'. Let these normal meet at point N. Then GN = ND = r = the radius of circular arc. Let ∠GND=OKO' = θ

Then in angle KOO'…… $\tan\theta = \frac{OO'}{KO}$ and the angle θ is small enough,

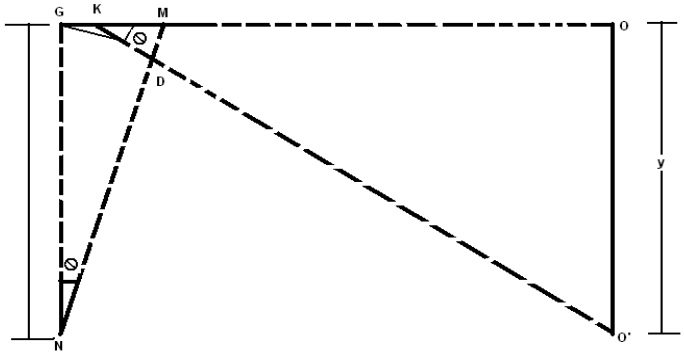


Figure 5

$$\theta = \tan\theta = \frac{y}{L}$$

Where L is distance of the screen from mid point of magnetic field region (generally mid point of electric field too).

$$\text{Again } \theta = \tan\theta = \frac{\text{arc GD}}{r} = \frac{GM}{r} \quad \text{since GD is nearly equal to GM.}$$

$$\text{Or } \theta = \frac{l}{r}$$

Where *l* is the length of the region of magnetic field equals to electric field too. By comparing both values of θ.

$$\frac{l}{r} = \frac{y}{L}, \text{ so } r = \frac{lL}{y} \qquad \ldots 8$$

Substituting values of r into …7,

$$\frac{e}{m} = \frac{Ey}{B^2 l L} \qquad \ldots 9$$

If a potential difference of V volts is applied between the plates P-P, and d is the gap between both plates than, the electric field is given by, E = V / d

Therefore,

$$\frac{e}{m} = \frac{Vy}{B^2 lLd} \qquad \ldots 10$$

Where y = distance between spot positions displayed on the screen of CRT in centimeters.

l is the length of the deflection plates. L is the distance between screen and plates, d is the distance between plates, V is applied DC voltages across plates and B is magnetic field strength determined by B = H tan ∠ where H is the Horizontal component of earth's magnetic field at that place.

Procedure:

Note: While performing experiments keep other electronics equipment away from the e/m setup.

1. Using compass needle, find and note **North-South** and **East-West** directions. Place CRT in between stand in such a way that its screen is faced towards North and both arms of stand to East – West direction.
2. Adjust the **Intensity** and **Focus** potentiometer in its mid position.
3. Connect the CRT to octal socket of instrument (socket provided upon the panel). Care should be taken while inserting CRT plug.
4. Keep instrument to south direction far from CRT.
5. Select **Polarity** selector switch at '**0**' position.
6. Set the Deflection Voltage potentiometer at anti clockwise direction.
7. Switch on the Power Supply and wait for some times (3-5 minutes) to warm up the CRT. A bright spot appears on the screen.
8. Adjust intensity and focus controls to obtain sharp spot.
9. Bring the spot at the middle position of the CRT by the help of X-plate deflection voltage pot given to back side of the instrument.
10. Set polarity selector to '+' position, adjust **Deflection Voltage** to deflect the spot 1cm away towards upward. Note the deflection voltage from the meter as **V1** and spot deflection as **y**.
11. Now place the bar magnets (on the stand arm) to both sides of CRT such that their opposite pole faces each other.

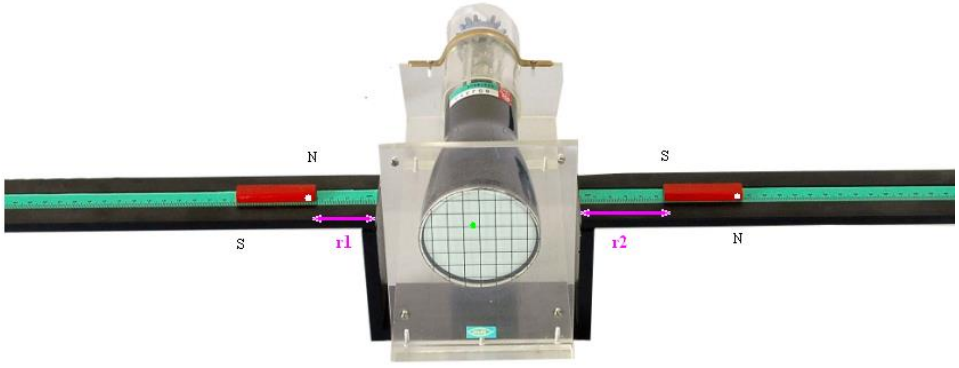


Figure 6

12. Adjust position of magnets to get spot back downward to original position.
13. Note the distances of bar magnet (poles facing the screen) as $\mathbf{r_1}$ and $\mathbf{r_2}$ from the scale.
14. Now remove magnets from the arms of stand.
15. Select '–' **position** from polarity switch. Apply DC voltage to deflect the spot 1 cm away in downward direction. Note deflection voltage from display as **V2** and deflection as y.
16. Place bar magnets again and adjust the position of magnets to bring spot back to original position. Note the distance of the magnets (poles facing the screen) as $\mathbf{r_1'}$ and $\mathbf{r_2'}$.
17. Remove CRT and magnets. Place Magnetometer arrangement in between stand such that its centre lies on the center of the stand arm. **Note:** Position of stand should not be disturbed.

18. Rotate Magnetometer and adjust the needle to read 0º - 0º.

19. Now place magnets at a distance equal to $\mathbf{r_1}$ & $\mathbf{r_2}$ as previous polarity adjusted. The pointer deflects along the scale. Note the deflections as $\boldsymbol{\theta_1}$ and $\boldsymbol{\theta_2}$.

20. Repeat similar procedure placing magnets at $\mathbf{r_1}'$ and $\mathbf{r_2}'$ distances. Note the deflection of compass needle as $\boldsymbol{\theta_3}$ and $\boldsymbol{\theta_4}$.

21. Now we know that magnetic field

$$B = H \tan$$

Where

$$\theta = \frac{\theta 1 + \theta 2 + \theta 3 + \theta 4}{4}$$

$$H = \sim 0.37 \times 10^{-4} \text{ Tesla}$$

22. Calculate e / m using following formula

$$\frac{e}{m} = \frac{Vy}{B^2 lLd}$$

Where

Distance between plates **d** = 1.4 cm

Length of plates ***l*** = 3.23 cm

Distance between screen and plates ***L*** = 14.5 cm

Deflection Voltage **V = (V1+V2)/2**

Deflection in cm **y** = 1cm

23. Take more readings by repeating experiment and deflecting spot to other distances.

24. Calculate the % error as

$$= \frac{\text{Standard value} - \text{calculated value}}{\text{Standard value}} \times 100$$

Precautions and sources of error:

- The cathode ray tube should be handled carefully. There should not be any magnetic substance nearby the place of experiment.
- Axis of magnets and axis of tube should lie perpendicular to each other in same horizontal plane. To correct it loose the neck clamp of CRT and rotate CRT so the spot deflects right up/down with deflection voltage.
- When magnets are place upon the arms. It is better to move stand slightly back & forth to obtain maximum magnetic field at deflecting plates. It should be done before bringing spot back to original position.
- Rotate magnet (s) on there axis if spot does not come back to its original position.
- When direction of spot is reversed the direction of magnets should also be reversed.

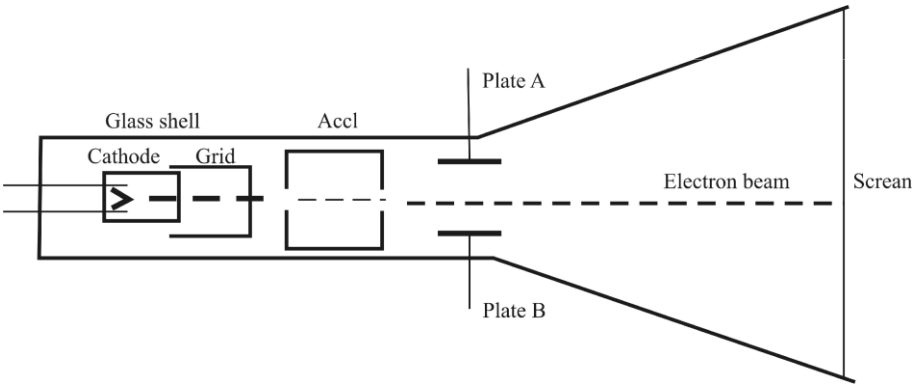
  The magnets should move tight to the scale in closest possible distances.
- The electric field between plates cannot be uniform due to shorter distance between them.
- The given constants are generally taken from data; there may be slight variations to produce error.

Specification of given CRT:

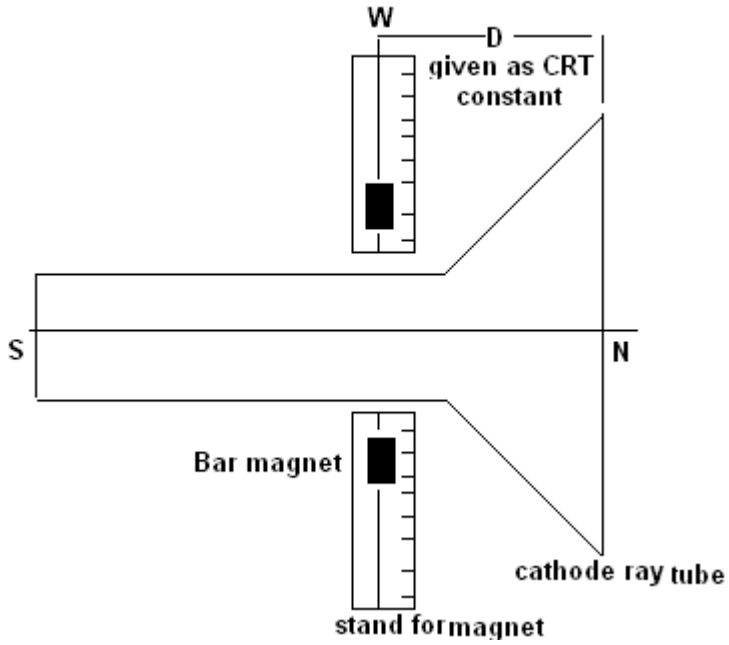
- Distance between plates, : d = 1.4 cm
- Length of plates : *l* = 3.23cm
- Distance between screen and plates (edge) : L = 14.5 cm

Standard Value of e/m:

$$\mathbf{e/m = 1.75888 \times 10^{11}\ C/Kg}$$



Cathode ray tube used in Thomson method



Way to place cathode ray tube

Experiment

AIM:- To find the thermal conductivity of a poor conductor by Lee's disk method

Introduction – Similar to the charge conduction phenomenon, heat also conducts through a material. The thermal conductivity is the property of a material independent of its dimensions. Alike current conduction, there are some good or some bad conductors of heat. Some materials like copper, aluminum, and iron are good conductors of heat whereas the materials like wood, glass etc. are bad conductors. The conductivity of a bad conductor can be measured by Lee's and Charlton method.

Theory –

Thermal Conductivity of a material is the rate of heat conduction through a material of unit thickness and unit cross-section area for each Kelvin of temperature difference (Fig. 1).

$$\boldsymbol{Ta} = \frac{\boldsymbol{Ha}\,(\boldsymbol{Q}) \times \boldsymbol{L}\,()}{\boldsymbol{Aa}\,(\boldsymbol{A}) * \boldsymbol{Ta}\,(\Delta \boldsymbol{T})}$$

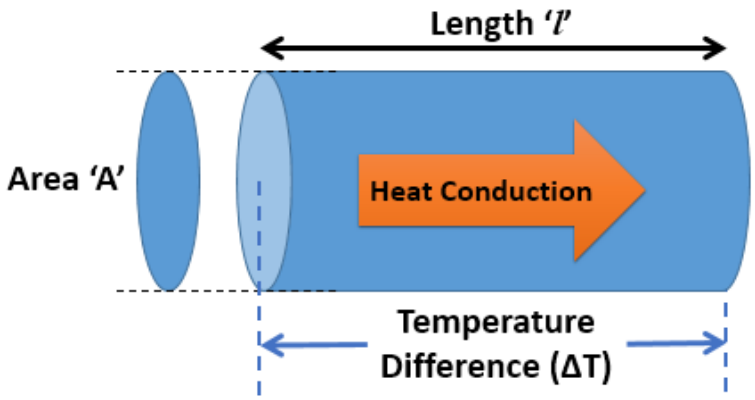


Fig. 1

The principle of this experiment is that at steady state, there will be constant temperature difference across the bad conductor and the rate of heat flow is constant. In the determination of thermal

conductivity of the bad conductor, the rate of flow of heat through the bad conductor is equated to the rate of loss of heat through the lower metal disc by heat radiation.

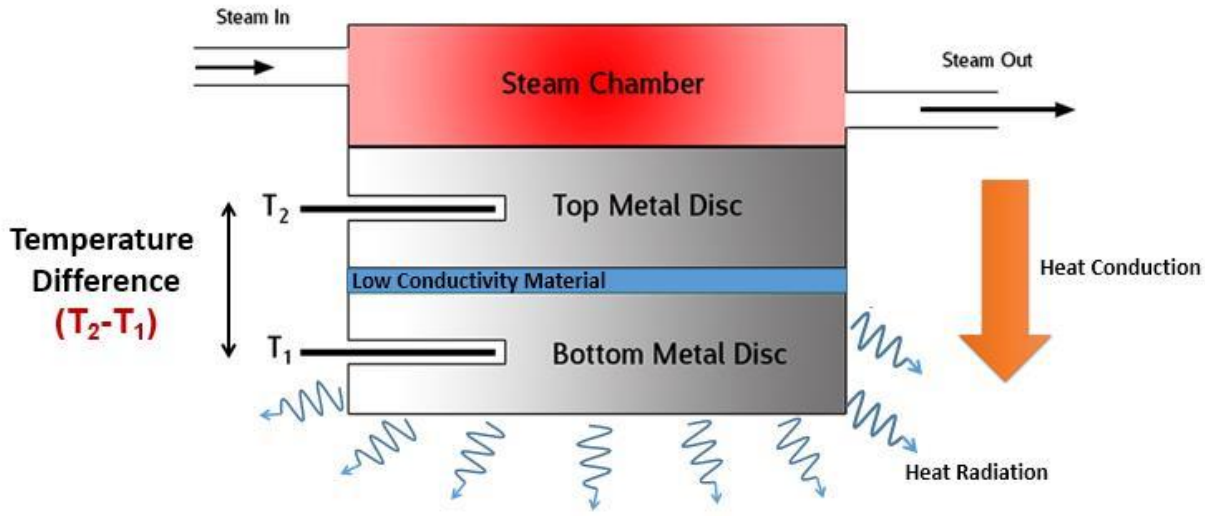


Fig. 2

$$Q = \frac{A(T - T)}{} = (T/)$$

$$= \frac{(T/)}{A(T - T)}$$

Where

k - Thermal conductivity of the sample, ***A*** - Surface area of the sample disc

T_2 - T_1 - Temperature difference across the sample, ***x*** - Thickness of the sample disc

'***m***' and '***s***' are the mass and specific heat of the bottom disc.

Aim – To calculate the thermal conductivity of a given bad conductor using Lee's and Charlton method.

Apparatus – A steam chamber, two metal discs, bad conductor in the form of a disc, a burner, water container, rubber pipe, 2 thermometers, 1 stop watch, a screw gauge and a measuring balance.

Diagram –

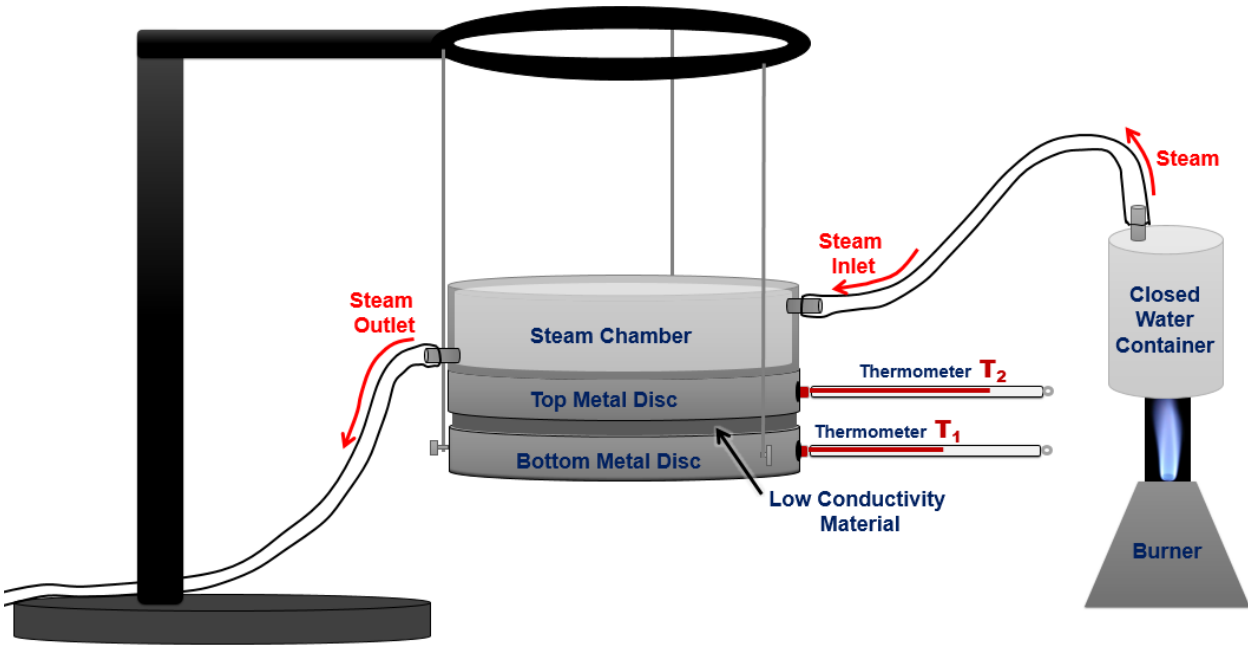


Fig. 3

Procedure –

1. Determine the thickness (x) of the bad conducting material disc using screw gauge (Table 1). Determine the diameter and then calculate the area (A) using vernier calipers (Table 2).

2. Arrange the apparatus as shown in the figure and start passing steam from the steam chamber (Fig. 2).

3. Note down the temperature of top (θ_2) and bottom metal discs (θ_1) after every 2 minutes (Table 3) until they reach a steady state and don't change further (This may take 20-30 minutes). Note down this temperature as steady state temperature of top (T_2) and bottom metal disc (T_1).

4. Now, Remove the 'Low Conductivity Material' and let the bottom plate heat to T_1 +10 ^oC.

5. Now remove the Top Metal disc and put the low conductivity material back on the bottom metal disc and observe the change in its temperature from T_1+10 to T_1-10 ^oC with respect to time (Table 4).

6. Plot the cooling curve of bottom metal disc and calculate the rate of cooling by calculating the slope ($\boldsymbol{T}/$) at temperature T_1.

7. Finally Apply the formula –

$$= \frac{(\boldsymbol{T}/)}{\boldsymbol{A}(\boldsymbol{T} - \boldsymbol{T})}$$

Here *m* and *s* are the mass and the specific heat of the bottom metal disc. x and A are the thickness and Area of Low Conductivity Material Disc.

Result: The thermal conductivity of a given poor conductor by Lee's and Charlton's method is found to be…….$Wm^{-1}K^{-1}$

Table –

Table 1 for the thickness of bad conductor disc –

Least Count (LC) of the Screw Gauge ……..

Sr. No.	Main Scale Division	Circular Scale Division	MSD + (CSD × LC)
1.			
2.			
3.			
		Mean Thickness -	

Table 2 for the diameter of bad conductor disc –

Least Count (LC) of the Vernier Calipers ……..

Sr. No.	Main Scale Division	Circular Scale Division	MSD + (CSD × LC)

1.			
2.			
3.			
		Mean Diameter (d) -	

Area of the Disc – $\pi(d/2)^2$ = …….

Table 3 for getting the steady state –

Sr. No.	Temperature of Upper Metal Disc (θ_2)	Temperature of Lower Metal Disc (θ_1)
1.		
2.		
3.		
4.		
5.		
…		
…		

Table 4 for the rate of cooling –

Sr. No.	Time (Minute)	Temperature of Lower Metal Disc
1.	1	
2.	2	
3.	3	
4.	4	

Experiment

AIM:- To study Hall effect and to measure carrier concentration and Hall coefficient for unknown semiconductor.

The **Hall Effect Setup** is a very useful system for the laboratory. It is used for the study and measurement of Hall Effect.

The Hall Effect is an important observation in its material science. If an electric current flows through a conductor in a magnetic field, it exerts a transverse force on the moving charge carriers, which tends to push them to one side of the conductor. It will balance this magnetic influence, producing a measurable voltage between two sides of the conductor, this voltage is Hall Voltage.

This system is provided with Gauss and Tesla meter with a sensor for measurement of magnetic field Measurement unit With LCD Display and PC interface for measuring hall voltage, probe current, heater current, Temperature, Hall Effect probe for the study of Hall Effect, constant current power supply with LCD display and electromagnet to produce magnetic field.

By this we can calculate carrier density, mobility of charge carrier, hall coefficient etc. We can study the effect of temperature in semiconductor, relation between magnetic field and hall voltage.

Setup consists of the following:

Gauss and Tesla Meter (InAs probe)

Measurement Unit

Constant current power supply

Electromagnet

Hall probe with Oven and Thermocouple

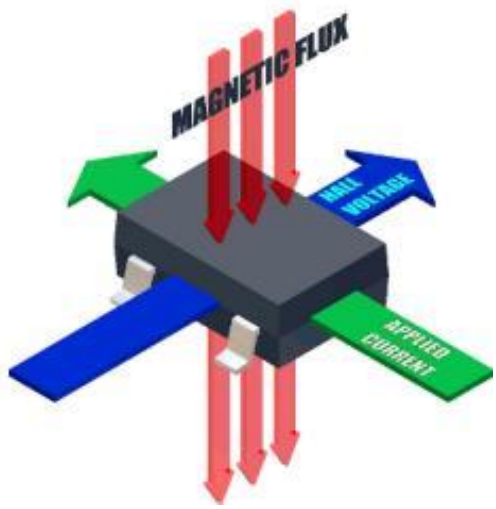


Theory

The Hall Effect is one of the rich sources of information about the conduction properties of semiconductors. The mobility and carrier concentration can be obtained from the Hall constant in conjunction with the resistivity; this cannot be done with the resistivity alone. The mobility is pertinent to the understanding of transistors since such things as high- frequency cut-off and the intrinsic current gain of the transistor are related to the property of germanium. The Hall Effect and associated thermo magnetic and galvano magnetic effects are discussed. The elimination of the effect of associated phenomena from the Hall measurement can be achieved in several ways.

Hall Effect

The Hall Effect comes about due to the nature of the current flow in a conductor. Current consists of the movement of many small charge-carrying "particles" (typically, but not always, electrons). These charges experience a force, called the Lorentz Force, when a magnetic field is present that is not parallel to their motion. When such a magnetic field is absent, the charges follow an approximately straight, 'line of sight' path. However, when a perpendicular magnetic field is applied, their path is curved so that moving charges accumulate on one face of the material. This leaves equal and opposite charges exposed on the other face, where there is a dearth of mobile charges. The result is an asymmetric distribution of charge density across the hall element that is perpendicular to both the 'line of sight' path and the applied magnetic field. The separation of charge establishes an electric field that opposes the migration of furthe r charge, so a steady electrical potential builds up for as long as the current is flowing.



In the Hall Effect, magnetic flux perpendicular to the flow of

An electrical current results in a measurable voltage

Hall Effect in Semiconductors

The simple formula for the Hall coefficient given above becomes more complex in semiconductors where the carriers are generally both electrons and holes which may be present in different concentrations and have different mobility. For moderate magnetic fields the Hall coefficient is

Where n is the electron concentration, p the hole concentration, μ_e the electron mobility, μ_h the hole mobility and e the electronic charge. For large applied fields the simpler expression analogous to that for a single carrier type holds.

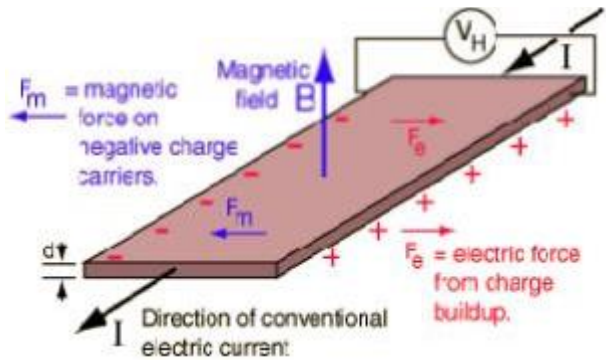
$$R_H = \frac{\quad}{\quad}$$

If an electric current flows through a conductor in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers which tends to push them to one side of the conductor. This is most evident in a thin flat conductor as illustrated. A buildup of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. The presence of this measurable transverse voltage is called the Hall Effect after E. H. Hall who discovered it in 1879.

Note that the direction of the current I in the diagram is that of conventional current, so that the motion of electrons is in the opposite direction. That further confuses all the "right-hand rule" manipulations you have to go through to get the direction of the forces.

Hall Effect

If an electric current flows through a conductor in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers which tends to push them to one side of the conductor. This is most evident in a thin flat conductor as illustrated. A buildup of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. The presence of this measurable transverse voltage is called the Hall Effect after E. H. Hall who discovered it in 1879. Note that the direction of the current I in the diagram is that of conventional current, so that the motion of electrons is in the opposite direction. That further confuses all the "right-hand rule" manipulations you have to go through to get the direction of the forces.



The Hall voltage is given by

$$V_H = \frac{\quad}{\quad}$$

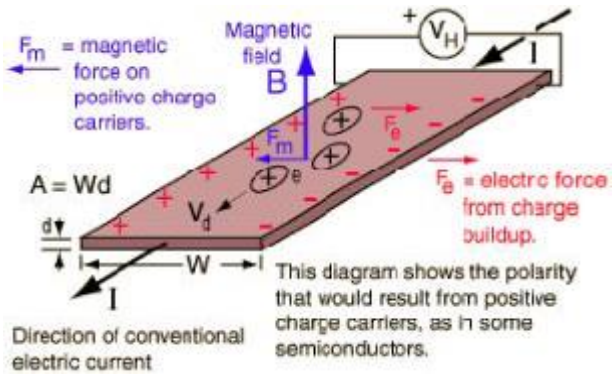
n = density of mobile charges

e = electron charge

The Hall Effect can be used to measure magnetic fields with a Hall probe

Hall Voltage for Positive Charge Carriers

The transverse voltage (Hall Effect) measured in a Hall probe has its origin in the magnetic force on a moving charge carrier.
The magnetic force is $F_m = eV_dB$ Where V_d is the drift velocity of the charge.



The current expressed in terms of the drift velocity is

$$I = neAv_d$$

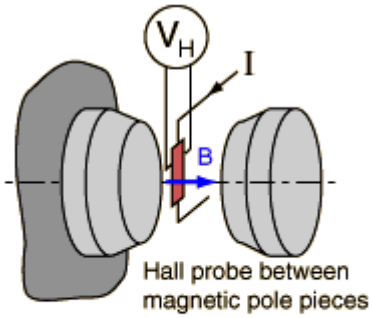
Where n is the density of charge carriers. Then

$$F_m = F_e$$

One very important feature of the Hall Effect is that it differentiates between positivecharges moving in one direction and negative charges moving in the opposite. The Hall Effect offered the first real proof that electric currents in metals are carried by moving electrons, not by protons. The Hall Effect also showed that in some substances (especially semiconductors), it is more appropriate to think of the current as positive "holes" moving rather than negative electrons.

Hall Probe

The measurement of large magnetic fields on the order of a Tesla is often done by making use of the Hall Effect. A thin film Hall probe is placed in the magnetic field and the transverse voltage (on the order of microvolt) is measured.

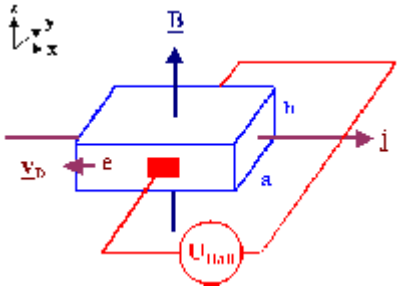


The polarity of the Hall voltage for a copper probe shows that electrons are the charge carriers.

Sometimes a thin copper film of thickness d on the order of 100 micrometers is used for a hall probe This subchapter introduces two important topics: The Hall effect as an important observation in materials science and at the same time another irrefutable proof that classical physics just can't hack it when it comes to electrons in crystals. The Hall Effect describes what happens to current flowing through a conducting material – a metal, a semiconductor – if it is exposed to a magnetic field *B*.

We will look at this in classical terms; again we will encounter a fundamental probl em the standard geometry for doing an experiment in its most simple form is as follows

A magnetic field *B* is employed perpendicular to the current direction j, as a consequence a potential difference (i.e. a voltage) develops at right angles to both vectors



In other words: A Hall voltage U_{Hall} will be measured perpendicular to *B* and *j*.

There may be almost as many means of sensing position and level as there are applications requiring these functions. Inductive, capacitive, mechanical, magneto- resistive, Hall Effect, and optical, to name just a few, are all viable sensing options and the list continues to expand. Yet for a designer, there always remain the same critical elements that need to be addressed and that inevitably mate the requirements of the application to the appropriate sensing technology. Critical requirements, such as: cost, distance of travel (effective operating air gap), resolution, accuracy, and often times cost again, all need to be determined to effectively and efficiently select the proper sensing technology. Of course, constructing answers for each of these elements is not always a straightforward task. Here, though, the flexibility of Hall-effect sensing technology is most advantage- either digital or analog output. The former option is optimal for sensing discrete positions,

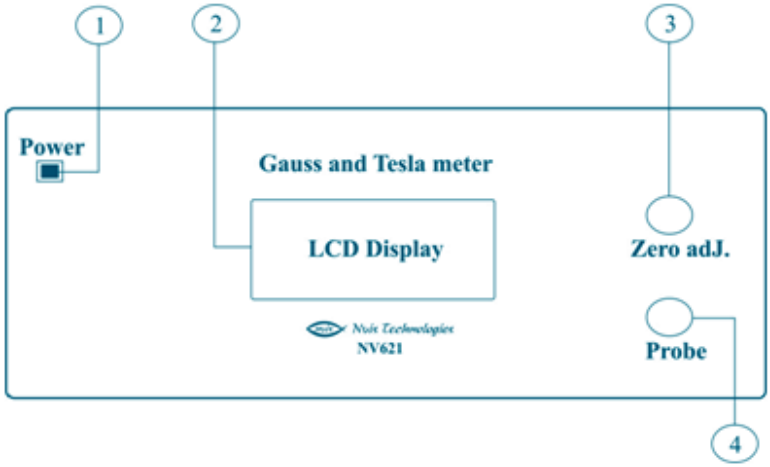
while the latter affords the user a relatively infinite number of positions for greater resolution. Some examples of applications requiring discrete position or level sensing are: automotive shift selectors, seat belt buckle switches, seat position sensors, cellular flip phones, and brushless dc motor commutation, windshield wiper fluid reservoirs, and gas tanks, to name just a few. Due to its high reliability, Hall-effect technology is used to replace reed switches and mechanical switches in these applications.

Most Hall-effect switches have output structures that are open drain and provide low resistance, thus simplifying the interface to most microprocessors and other digital electronics (threshold comparators, multiplexers, basic TTL gates, and so forth). Typical of open-drain outputs, once switched "on," the output voltage of the Hall-effect device transitions from high to low. This being said, there is an abundance of variations for Hall-effect sensors in order to service to the plethora of position and level sensing applications, each one with its own nuances. These variations include features such as: micro-power consumption (A3211,-12, -13, and -14), magnetic pole-independent sensing (A3425), user-programmable options (A3250, and -51 and A1182, -83, -84,-85, and -86), two-wire current sourced output devices (A1142,-43, -44, -45, -46, -47, and -48 and A1182, -83, -84, -85, and -86) magnetic bias for sensing ferrous targets (ATS6*xx*), and inverted outputs (A3211). These cannot all be adequately discussed in one sitting, and for the purpose of this article, the focus will be on standard devices: their operation and application uses.

Gauss and Tesla meter Gauss and Tesla meter is used to measure the magnetic field. It operates on the principal of Hall Effect. When a semiconductor carrying current place in a magnetic field direction of current and magnetic field should be perpendicular to each other an electromagnetic force develops which perpendicular to both field. This e.m.f. is small in magnitude .this voltage is amplified by a high stability amplifier circuit so that a milivoltmeter connected at the output of the amplifier can be calibrated directly in magnetic field.

Sensor	**:**	InAs for better sensitivity
Special feature	**:**	Indicate the direction of the magnetic field
Mains	**:**	230V AC 10 %, 50Hz

Panel Control:



Front Panel Control:

1. **Power:** It is power on/off switch.
2. **LCD Display:** For monitoring magnetic field in Gauss and Tesla.
3. **Zero Adjust:** With the help of this potentiometer we can calibrate the meter for zero position
4. **Hall Probe:** It is input socket for connecting the probe.

Rear Panel:

1. **PC Interface:** we can connect a RS232 cable for connecting the meter with PC

Precautions:

Take care the InAs probe is very delicate cover it after use.

Measurement Unit

Microcontroller Based LCD Display for Measurement of Hall Voltage, Probe current, Heater current and Temperature With PC Interface facility.

Specifications

Crystal : P- type Ge Semiconductor **Hall**

Voltage : 0-200mV (100microvolt Min) **Probe**

Current : 0 – 20mA

Heater Current : 0 – 700mA

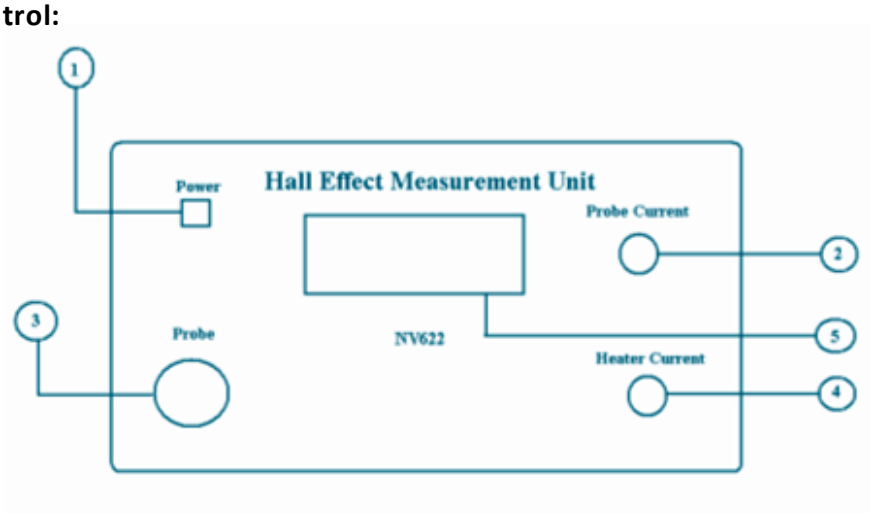
Temperature : 0-100^{0}C

Line Regulation : 0.1% for 0 to full load

Load Regulation : 0.03% for 0 to full load

Mains : 220V AC ± 10% /50Hz

Panel Control:



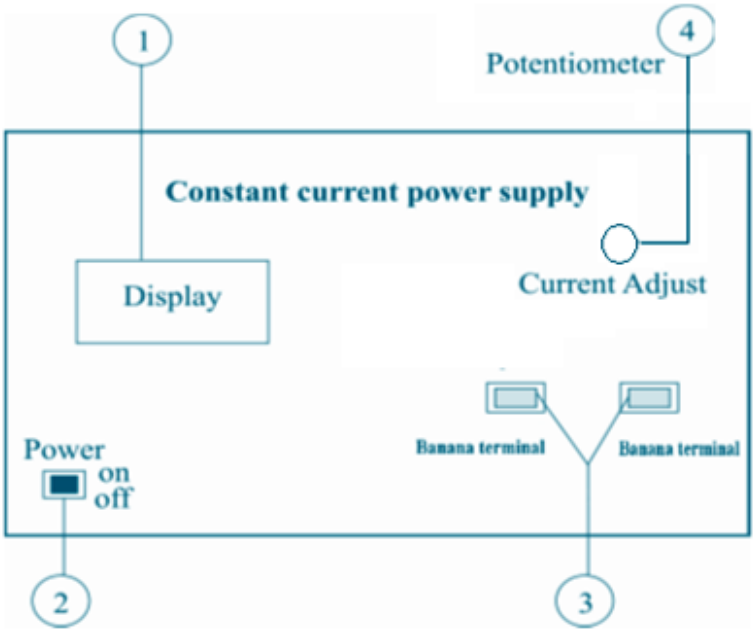
1. **Power:** Push button switches for supplying the power to the instrument.
2. **Probe Current:** with the help of this potentiometer we can vary and increase current in crystal
3. **Probe:** This is the input socket for connecting the Hall Effect probe.
4. **Heater Current:** By this potentiometer we can increase the heater current.
5. **LCD Display:** It displays Probe current, Hall Voltage Heater current temp.

Constant Current Power Supply

Specification

Current	:	0 to 3.5A
Voltage	:	20V
Mains	:	220V AC ± 10% /50Hz

High stability and regulation



Panel control

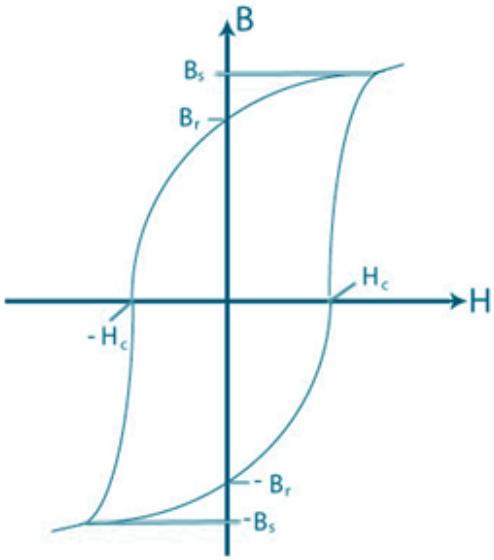
1. **LCD Display:** It shows the output current.
2. **Power:** It is power on/off switch.
3. **Output:** For connecting the electromagnet.
4. **Current Adjust:** By this we can adjust the current.

Precautions

Always increase or decrease the current gradually & switch on or off the Power supply at the zero current position.

Hysteresis in Electromagnet and How to reduce it

When current is passed through coil a temporary magnet is formed in the poles of the electromagnet. The material of the poles has some magnetic hysteresis. So a residual magnetic field or remnants magnetization, B_r is generated even when no current is passed in the coil. Please refer to the figure below.



The field required to reduce the magnetisation of the sample to zero is called the coercive field H_C. In the case of Electromagnet this field is applied by changing the direction of the current in the coil.

Method for reducing the remnant magnetization:



1. Make the air gap between the poles of the electromagnet equal to 20 mm.
2. Connect the electromagnet to the constant current power supply polarity wise and check the magnetic field in air gap with the help of Gauss and Tesla meter.
3. Increase the current in the coil so that maximum field is generated between the air gaps.
4. Now reduce the current in coil to zero and disconnect electromagnet.
5. Again check the magnetic field between the air gaps. There would be some magnetic field shown due to Hysteresis Effect. (Say 150 Gauss).
6. Now to reduce it, connect the electromagnet to the constant current supply in reverse polarity(red cable in black terminal and black cable in red terminal).
7. Increase the current slowly and simultaneously check the value of magnetic field in Gauss and Tesla meter. When current is increased the magnetic field is reduced to zero and when more current is supplied magnetic field value will become negative. The current should be increased such that a slightly more negative value equal to positive value is achieved (in our case -150 to -200 Gauss).
8. Switch off the constant current supply and remove the connection of lectromagnet. Then check the value of magnetic field in the gap. Now it should be

very close to zero.

Objective: To measure the Hall voltage

Items Required

1. Gauss and Tesla meter
2. Measurement unit
3. Constant current power supply
4. lectromagnet
5. Hall probe
6. InAs probe.

Procedure

1. Take Constant Current Power Supply & set the Current Adjust potentiometer at fully anticlockwise position. Connect electromagnet with Constant Current power supply such that two coils of electromagnet is in series i.e. the direction of current in both the coils should be same otherwise little or no magnetic field would results.
2. Keep the Poles of electromagnet at some distance of 20mm.
3. Take Gauss & Tesla meter from the set of Hall Effect Setup .
4. Connect InAs probe and switch on the Gauss & Tesla meter.
5. Adjust zero reading on display by Zero Adjust potentiometer and keep ready for measurement.
6. Now take measurement unit and set it as follows
   a. Heater current potentiometer at minimum position (anticlockwise position).
   b. Probe current potentiometer at minimum position (anticlockwise position).
7. Connect Hall Probe in given probe socket
8. Switch on the Constant Current Power supply and set some low value of current.
9. Switch on the Measurement unit and increase probe current by probe current potentiometer and fix it at 5mA.
10. There may be some voltage reading even outside the magnetic field. This is due to imperfect arrangement of the four contact of the hall probe and generally known as the "Zero field potential . In all cases, this error should be subtracted from the hall voltage reading as we consider it as a reference.
11. Now place the Hall probe between magnetic poles using stand such that the magnetic and electric field should be perpendicular to each other.
12. Due to this arrangement a force is generated in semiconductor, therefore a potential difference is developed in semiconductor wafer, which is perpendicular of both field (magnetic and electric). This potential difference is called Hall voltage.
13. You can measure & record this potential difference on the display

14. Measure Hall voltage for both sides of probe

15. Subtract Zero field potential and take the mean of both sides Hall voltages readings. This is Hall voltage VH

Observation Table

Probe Current I(mA)	Magnetic Field B(Tesla)	Zero field Potential (offset voltage) V_{zero}	Hall voltage for one side of the probe With offset Voltage (V_H^+)	Hall Voltage for Second side with offset Voltage (V_H^-)	Hall voltage for one side without Offset voltage ($V^+ = V_H^+$	Hall voltage for second side without offset voltage ($V^- = V_H^- - V$	Mean Voltage V_H =

Objective: Calculate the charge carrier concentration (density) of given semiconductor wafer

Items Required

1. Gauss and Tesla meter
2. Measurement unit
3. Constant current power supply
4. Electromagnet
5. Hall probe
6. InAs probe.

Procedure

1. Take Constant Current Power Supply & set the Current Adjust potentiometer at fully anticloc kwise position. Connect electromagnet with Constant Current power supply such that two coils of electromagnet is in series i.e. the direction of current in both the coils should be same otherwise little or no magnetic field would results.
2. Keep the Poles of electromagnet at some distance of 20mm.
3. Take Gauss & Tesla meter from the set of Hall Effect Setup .
4. Connect InAs probe and switch on the Gauss & Tesla meter.
5. Adjust zero reading on display by Zero Adjust potentiometer and keep ready for me asurement.
6. Now take measurement unit and set the switch position as follows
   a. Heater current potentiometer at minimum position (anticlockwise position).
   b. Probe current potentiometer at minimum position (anticlockwise position).
7. Connect Hall Probe in given probe socket.
8. Switch on the Constant Current Power supply and set some low value of current.
9. Switch on the Measurement unit and increase probe current by probe current potentiometer and fix it at 5mA.
10. There may be some voltage reading even outside the magnetic field. This is due to imperfect arrangement of the four contact of the hall probe and generally known as the "Zero field potential. In all cases, this error should be subtracted from the hall voltage reading as we consider it as a reference.
11. Now place the Hall probe between magnetic poles using stand such that the magnetic and electric field should be perpendicular to each other.
12. Due to this arrangement a force is generated in semiconductor, therefore a potential difference is developed in semiconductor wafer, which is perpendicular of both field (magnetic and electric). This potential difference is called Hall voltage.
13. You can measure & record this potential difference on the display.

14. Measure Hall voltage for both sides of probe

15. Subtract Zero field potential and take the mean of both sides Hall voltages readings. This is Hall voltage VH.

Observation Table

Probe Current	Magnetic Field	Zero field Potential (o	Hall voltage for one side of the probe	Hall Voltage for Second	Hall voltage for one side without Offset	Hall voltage for second side without offset	Mean Voltage

16. Now we know that charge carrier density n can be calculated by

$$n = B \times I / VH \times t \times e$$

Where

n = carrier concentration, B = magnetic field

I = current of probe

VH = Hall voltage

t = Width of Hall crystal= Mention on the Hall Probe e = Electron charge=1.6×10^{-19} coulomb

Now put the all value in formula and calculate the charge carrier density.

Obective : Calculate the Hall coefficient of given semiconductor material

Items Required

1. Gauss and Tesla meter
2. Measurement unit
3. Constant current power supply
4. Electromagnet
5. Hall probe
6. InAs probe

Procedure

1. Take Constant Current Power Supply & set the Current Adjust potentiometer at fully anticlockwise position. Connect electromagnet with Constant Current power supply such that two coils of electromagnet is in series i.e. the direction of current in both the coils should be same otherwise little or no magnetic field would results.
2. Take Gauss & Tesla meter from the set of Hall Effect Setup.

   Connect InAs probe and switch on the Gauss & Tesla

   meter.
3. Adjust zero reading on display by Zero Adjust potentiometer and keep ready for measurement.
4. Keep the Poles of electromagnet at some distance of 20mm.
5. Now take measurement unit and set the switch position as follows
   a. Heater current potentiometer at minimum position (anticlockwise position).
   b. Probe current potentiometer at minimum position (anticlockwise position).

      Connect Hall Probe in given probe socket (Nvis 622).
6. Switch on the Constant Current Power supply and set some low value of current.
7. Switch on the Measurement unit and increase probe current by probe current potentiometer and fix it at 5mA.
8. There may be some voltage reading even outside the magnetic field. This is due to imperfect arrangement of the four contact of the hall probe and generally known as the "Zero field potential. In all cases, this error should be subtracted from the hall voltage reading as we consider it as a reference.
9. Now place the Hall probe between magnetic poles using stand such that the magnetic and electric field should be perpendicular to each other.
10. Due to this arrangement a force is generated in semiconductor, therefore a potential difference is developed in semiconductor wafer, which is perpendicular of both field (magnetic and electric). This potential difference is called Hall voltage.

11. You can measure & record this potential difference on the display. Measure Hall voltage for both sides of probe

Subtract Zero field potential and take the mean of both sides Hall voltages readings. This is Hall voltage V

Now we know that charge carrier density n can be calculated by

Observation table

Probe Current I(mA)	Magnetic Field B(Tesla)	Zero field Potential (offset voltage) V_{zero}	Hall voltage for one side of the probe With offset Voltage (V_H^+)	Hall Voltage for Second side with offset Voltage (V_H^-)	Hall voltage for one side without Offset voltage ($V^+ = V_H^+ - V_{zero}$)	Hall voltage for second side without offset voltage ($V^- = V_H^- - V_{zero}$)	Mean Voltage V_H =

n=B x I / VH x t x e

Where

N = carrier concentration

B = magnetic field

I = current of probe

VH = Hall voltage

t = Width of Hall crystal= Mention on the Hall Probe

e = Electron charge=$1.6x10^{-19}$ coulomb

Now put the all value in formula and calculate the charge carrier density.

Now for calculating the hall coefficient we have to use following formula

$R_H = 1/ne$

Where

R_H = Hall coefficient,

n = Carrier concentration or carrier density e = Electron charge

Put the value of n and e and find the hall coefficient.

Objective: Calculate the mobility of charge carrier (μ) Items

Required

1. Gauss and Tesla meter
2. Measurement unit
3. Constant current power supply
4. Electromagnet
5. Hall probe
6. InAs probe

Procedure

1. Take Constant Current Power Supply & set the Current Adjust potentiometer at fully anticlockwise position. Connect electromagnet with Constant Current power supply such that two coils of electromagnet is in series i.e. the direction of current in both the coils should be same otherwise little or no magnetic field would results.
2. Take Gauss & Tesla meter from the set of Hall Effect Setup .
3. Connect InAs probe and switch on the Gauss & Tesla meter.
4. Adjust zero reading on display by Zero Adjust potentiometer and keep ready for measurement.
5. Keep the Poles of electromagnet at some distance of 20mm.
6. Now take measurement unit and set the switch position as follows
   a. Heater current potentiometer at minimum position (anticlockwise position).
   b. Probe current potentiometer at minimum position (anticlockwise position).
7. Connect Hall Probe in given probe socket
8. Switch on the Constant Current Power supply and set some low value of current.
9. Switch on the Measurement unit and increase probe current by probe current potentiometer and fix it at 5mA.
10. There may be some voltage reading even outside the magnetic field. This is due to imperfect arrangement of the four contact of the hall probe and generally known as the "Zero field potential. In all cases, this error should be subtracted from the hall voltage reading as we consider it as a reference.
11. Now place the Hall probe between magnetic poles using stand such that the magnetic and electric field should be perpendicular to each other.
12. Due to this arrangement a force is generated in semiconductor, therefore a potential difference is developed in semiconductor wafer, which is perpendicular of both field (magnetic and electric). This potential difference is called Hall voltage.

13. You can measure & record this potential difference on the display.

14. Measure Hall voltage for both sides of probe

15. Subtract Zero field potential and take the mean of both sides Hall voltages readings. This is Hall voltage VH.

Observation Table

Probe Current I(mA)	Magnetic Field B(Tesla)	Zero field Potential (offset voltage)	Hall voltage for one side of the probe With offset	Hall Voltage for Second side with offset	Hall voltage for one side without Offset voltage (V^{+} - V_{+} - V_{zero})	Hall voltage for second side without offset voltage ($V^{-} = V_H^{-} - V_{zero}$)	Mean Voltage V_H =

16. Now we know that charge carrier density n can be calculated by

$$n = B \times I / VH \times t \times e$$

Where n = carrier concentration

B = magnetic field

I = current of probe

VH = Hall voltage

t = Width of Hall crystal = Mention on the Hall Probe

e = Electron charge=1.6×10^{-19} coulomb

Now put all the values in formula and calculate the charge carrier density.

17. Now for calculating the hall coefficient we have to use following formula

$$R_H = 1/ne$$

Where R_H = Hall coefficient,

n = Carrier concentration or carrier density e = Electron charge

Put the value of n and e and find the hall coefficient.

18. Now we know that carrier mobility

Where = conductivity

And we also that $\mu = R_H$

= 1/

It is specified that the resistivity of the given Ge crystal is

= “Mention on the Hall Probe” cm

Put the value of R_H and ne and find mobility.

Experiment

AIM: To

Study of V-I Forward Characteristics of Silicon diode

Study of V-I Reverse Characteristics of Germanium diode

Study of V-I Characteristics of Zener diode

Study of V-I Characteristics of Light Emitting Diode (LED)

Equipment Required

Si Diode, Zener Diode, Germanium Diode and Light Emitting Diode, voltmeter, ammeter, connecting wires, and multimeter

Theory and Introduction

SEMICONDUCTORS

Based on electrical conductivity, there are three classes of materials, Conductor, Semiconductors and Insulators. Semiconductors are those materials which have their conductivity lower than the conductors but higher than that of insulators. These semiconducting materials are used to manufacture many devices such asdiode, transistors, IC's (integrated circuits), MEMS (microelectromecahnicalsytems) and even nanodevices (example quantum dot leds') today. They are so widely used because of their special band gap and its related properties. Now band gap of a material is defined as the energy difference between conduction band and valence band in terms of electron energy. It is a major factor in deciding a material application for e.g. Conductors have no E_g, semiconductors have an E_g of the order of 1ev.

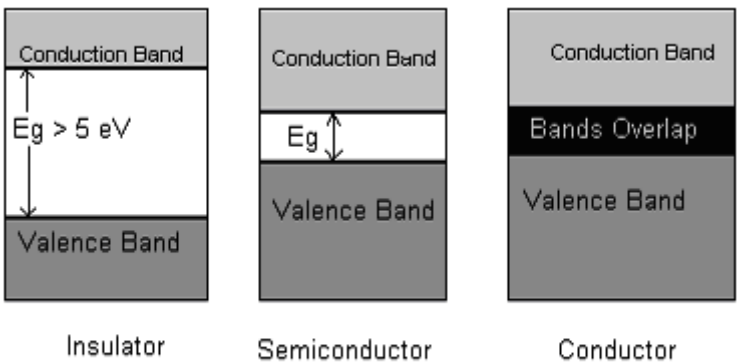


Fig. 3.1 Energy band diagram of an insulator, semiconductor and a conductor.

At room temperature, conductors have very high number of charge carriers in conduction band which gives high conductivity whereas for the case of insulators very few electrons reach the conduction band at room temperature. For semiconductors reasonable numbers of charge carriers reach the conduction band. There is a direct relation between intrinsic charge carrier concentration (n_i) and conductivities (σ). Since Ge has three orders of n_i greater than that of Si therefore its conductivity (σ) is also 3 orders higher. It is to be noted that they are both good conductors at room temperature.

The resistance of conductors increases with increase in temperature because the lattice vibrations block the free flow of electrons on application of potential. For the case of intrinsic semiconductor with increase in temperature, the resistance decreases because more electron hole pairs are generated due to breakage of bonds. With an addition of small amount of impurity (one in 10^7 atoms) from third group or fifth group, the conductivity increases by an order of 10^5. This is because the number of free charge carriers increases by 10^5 times (10^{12} / 10^7).

DIODES : FABRICATION AND CONSTRUCTION:

The diode is a device formed from a junction of n-type and p-type semiconductor material. The lead connected to the p-type material is called the anode and the lead connected to the n-type material is the cathode. In general, the cathode of a diode is marked by a solid line on the diode.

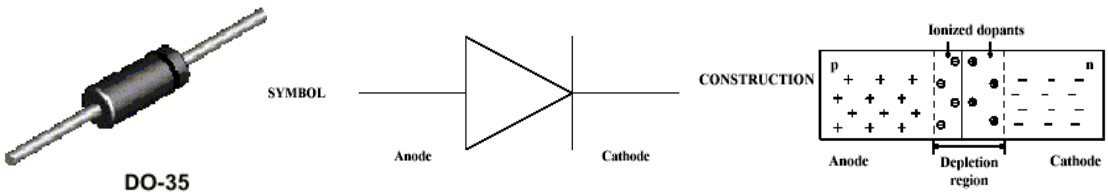


Figure 1. (a) a Diode, (b) Symbol of diode, (c) Depletion Layer in diode

POTENTIAL BARRIER

When the pn junction is made, there is a transfer of charge through the junction region because of concentration gradient of the charge carriers, as shown in fig 1.2. This creates a *barrier potential.*) The direction of barrier potential is as shown by the arrow from n type to p type**. It is the formation of potential barrier that makes the device useful since it can be controlled by various factors like biasing etc.**

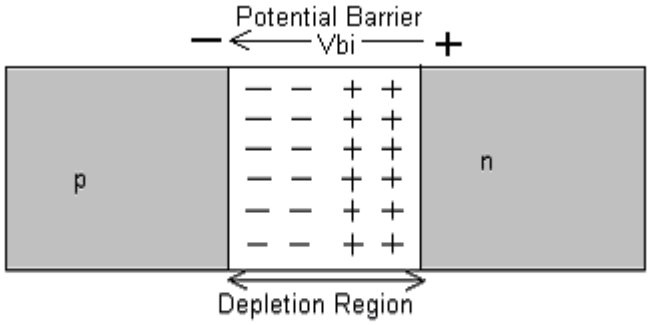


Fig. 3.2 Depletion Region consisting of uncompensated ions on both sides of the junction. The potential barrieier is from n side to p side.

The direction of this field is from n side to p side as shown in figure 2. The equation of this field barrier (Vbi) is given by

$$V_{bi} = \frac{kT}{q} \ln \frac{N_a N_D}{n_i^2} \qquad 3.1$$

where N_a and N_d are the acceptor and donor concentrations, n_i is the intrinsic concentration, q is the electron charge and T is the temperature in absolute values. $V_{bi}$is lesser for Ge (0.2 V) than for Si (0.6 V) since n_i is higher for Ge compared to Si.

BIASING

The primary function of the diode is rectification. **Forward Biasing:** If an external voltage is applied such that negative of battery is connected to n side and positive to the p side then V_{bi} will get reduced and more current can flow across the junction.

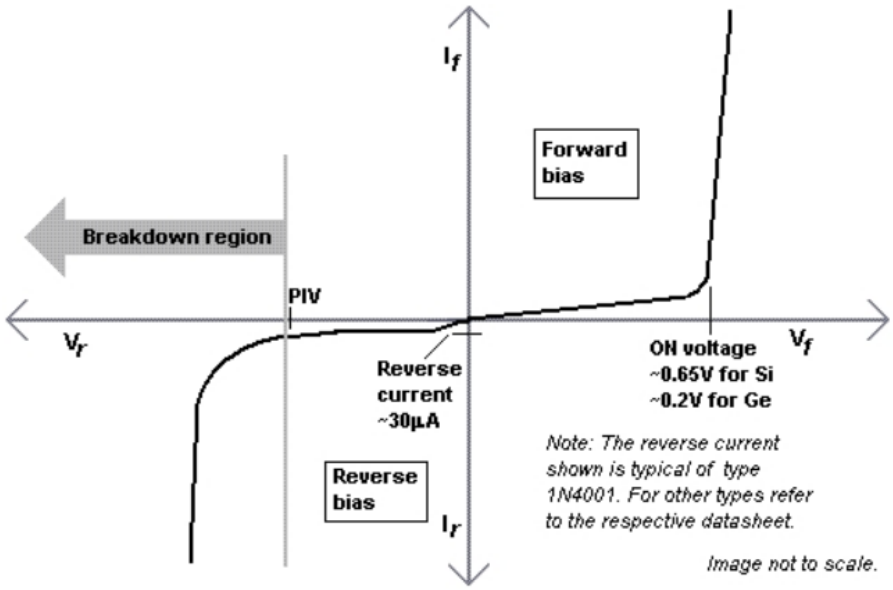
Reverse Bias On the other hand if an external voltage is applied in the reverse direction i.e. positive of battery to n side and negative of battery to p side then the barrier potential increases and only minority charge carriers flow across the junction. Thus the current is very small in microamperes and is independent of the external voltage, up to a certain voltage. Beyond this voltage, the diode breaks down by either Avalanche breakdown mechanism or Zener breakdown mechanism.

The primary function of the diode is rectification, so when it is forward biased (the higher potential is connected to the anode lead), it will pass current. When it is reversed biased (the higher potential is connected to the cathode lead), current flow is blocked. If a voltage V is applied across the diode, the current flowing across it is given by the Shockley equation

$$I = I_o \left(e^{\frac{v}{\eta V_t}} - 1 \right) \qquad 3.2$$

where V is the bias potential across the diode. The factor η is called ideality factor. $\eta$is 1 for Si and 2 for Ge diodes. V_t is volt equivalent of temperature and is given by 11,600 / T. Its value at room temperature is 26 mV. I_o is the reverse saturation current in mA which depends upon temperature and doping. This is called reverse saturation since its value cannot be increased by increasing Vr.

A general curve looks like this



PEAK INVERSE VOLTAGE (PIV):

PIV is the maximum reverse bias voltage which can be applied safely to a diode without its breaking down. Beyond this voltage a diode breaks down.

Avalanche Breakdown The minority carriers which are diffusing across the junction get sufficient energy from the increased voltage to break the covalent bonds and generate more Electron hole pairs. These generated pairs break more bonds and this process is multiplicative. Thus at the breakdown condition the current suddenly shoots up because of additional extra pairs.

ZENER breakdown This is applicable only to heavily doped junctions which have a very narrow depletion layer. On increase of reverse voltage the electric field increases so much that the covalent bonds break and generate minority carriers which constitute the reverse current.

MULTIMETER TEST OF DIODES

One can know whether a specific terminal of a diode is n or p by measuring the resistance with multimeter. To do so keep the multimeters in resistance mode connect its positive lead to the anode of diode and negative lead to its cathode. During the test,the multimeter passes current through the diode and the diode gets forward biased. It thus indicated very low resistance of the order of 100 Ω . If the leads are now reversed than the diode gets reverse biased and offers very high resistance of the order of MΩ. This can be read in the multimeter again. If a diode reads very low resistance in the forward as well as reverse bias then it is fused. On the other hand if it reads high resistance in the forward as well as reverse bias then it is open.

Table 3.1 gives the comparison of Si and Ge diodes in terms of band gap (E_g) V_{bi} and, PIV

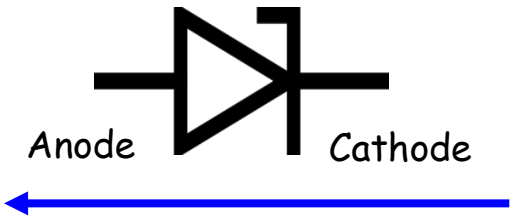
TABLE 3.1.

Diode Material	E_g (ev)	V_{bi} (V)	PIV (V)
Ge Diode	0.785	0.2	400
Si Diode	1.21	0.6	1000

It is clear that Si diodes have an advantage over Ge diodes since their band gap is more and they have a higher PIV. If the band gap is more they are more impervious to temperature changes since there is a direct relation between Eg and working temperature. But Ge diodes are more useful for switching circuits since their Vbi is almost 0 V.

The Zener Diode

The zener diode is a very useful device which is designed to be used in reverse bias (i.e. the cathode is more positive than the anode). As we have seen in a normal silicon diode, diodes do not conduct in the reverse direction at all, but with some careful processing at the manufacturing stage it is possible to alter the behaviour of the diode to that it does conduct in the reverse direction, but only at one specific voltage called the zener voltage V_Z. The zener diode is given a different circuit symbol to ensure that it can be easily identified which is shown below.



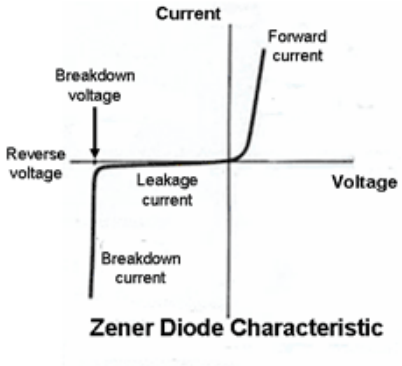
Conventional current flows easily in this direction

only when the cathode is **above** the zener voltage, V_Z.

The physical appearance of a Zener diode is much the same as a normal silicon diode, however the case is usually made of glass rather plastic, although this should not be taken as the only way to identify a zener diode.



The electrical characteristic of the Zener diode is an easily identifiable characteristic as shown below.



Note : the forward characteristic is exactly the same as for a silicon diode.

The breakdown voltage, V_Z, can be controlled by the manufacturing process and a whole range of values are available. e.g. 3.3V, 3.9V, 4.7V, 5.1V, 6.8V etc.

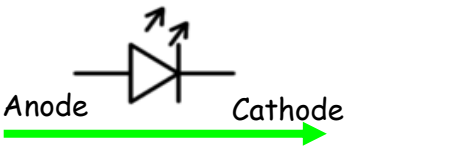
Another important parameter to bear in mind with zener diodes is the power rating of the diode, this is important because the zener diode could have a considerable voltage across it whilst carrying a significant current, and therefore power dissipation will be very important. You should remember that Power = Voltage x Current, so calculating the power dissipated in a zener diode is a relatively straightforward calculation to perform.

Light Emitting Diodes

Our final variant on the diode theme, is the light emitting diode or L.E.D. for short, which as it's name suggests gives off light when current passes through it. The L.E.D. is an extremely useful device which has revolutionised indicator panels over the last ten to fifteen years. The L.E.D. has virtually replaced filament lamps in electronic circuits as it offers considerable advantages over filament lamps. For example

- Operate on much lower voltages
- Give off an acceptable level of light with just a few milliamps of current passing through them.
- Last much longer than filament bulbs.
- Are available in a variety of shapes, sizes and colours.
- Basic versions are now very cheap.

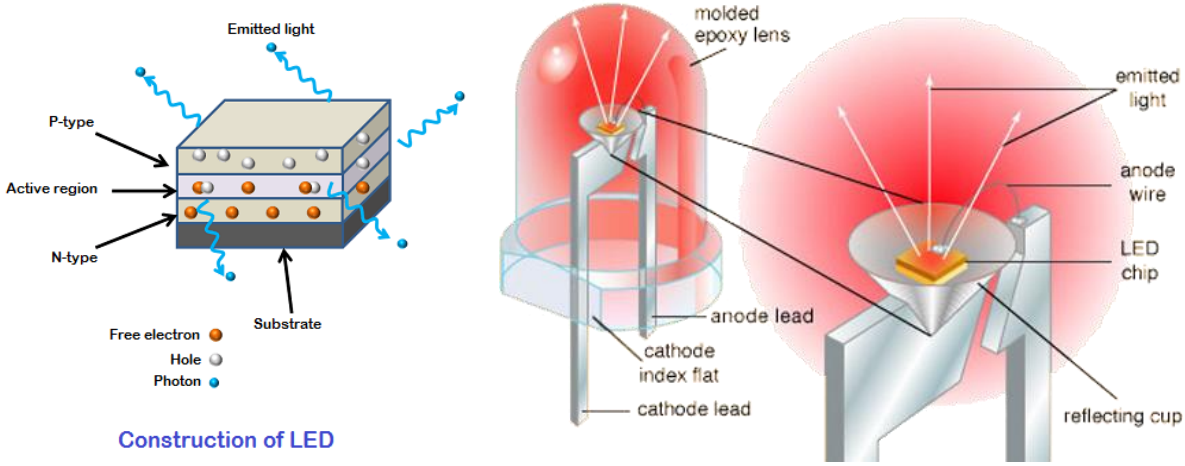
The l.e.d. also has it's own unique symbol



Light given off when conventional current flows in this direction

The following pictures shows a small sample of the range of l.e.d's available (left), and the various ways in which they can be packaged (right).

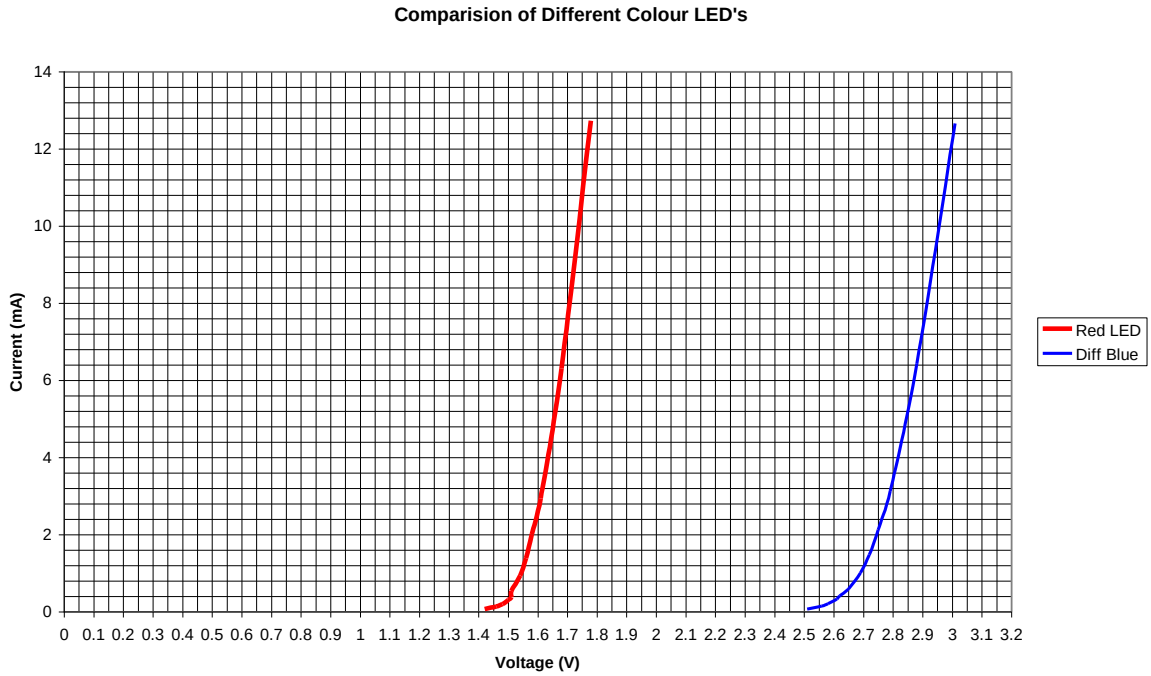




Construction of LED

Figure: Construction of LED

The characteristic curve for an L.E.D. is also very similar to that of the silicon diode, with the only exception being that the voltage at which current starts to flow is a little higher, and depends on the colour of The L.E.D. The characteristic curves for a red and blue l.e.d. are shown below.



We usually try to arrange for a minimum current of approximately 10mA to flow through an L.E.D. to give a satisfactory light output and if this is the case we can see that the voltage across the red L.E.D. would be approx 1.75V, and 2.95V across the blue L.E.D. (Note: Some L.E.D'S, particularly hi-intensity and ultra bright versions may require more current for full illumination up to 40mA, so check the manufacturers data sheet if using these in projects.) One thing we have to be very careful about with L.E.D'S is that they are not very good at handling reverse bias, indeed if a reverse bias of more than 5V is applied to the L.E.D. then it will usually be damaged permanently. Correct identification of the anode and cathode is therefore very important when using L.E.D.'s in practical circuits. (More information on this will be found in the Practical Circuit Assistance Module)

Procedure and Experimental Setup

A current vs. voltage plot is called the *I-V Characteristic* of the device. The basic circuit to determine the current–voltage characteristic is given below in fig. 3. The voltage across any device to be studied is varied by changing the output of a power supply (see Figure 3). Voltages and corresponding currents are measured by voltmeter and ammeter respectively. Such a plot yields much useful information.

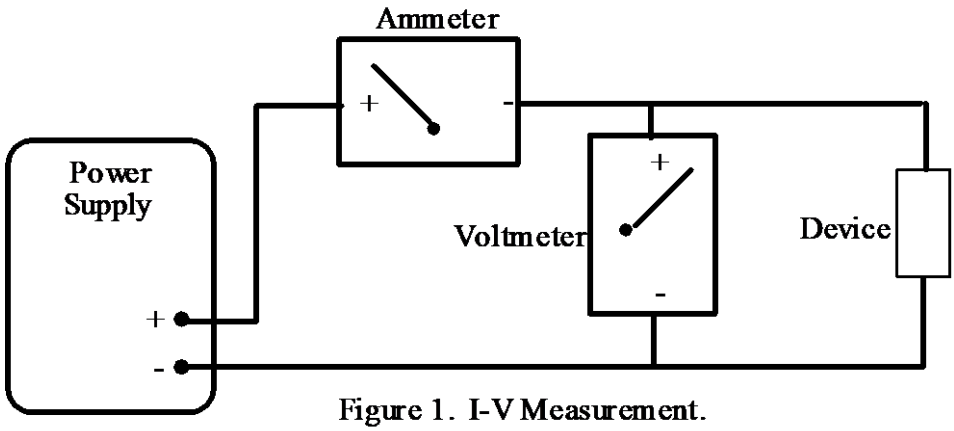
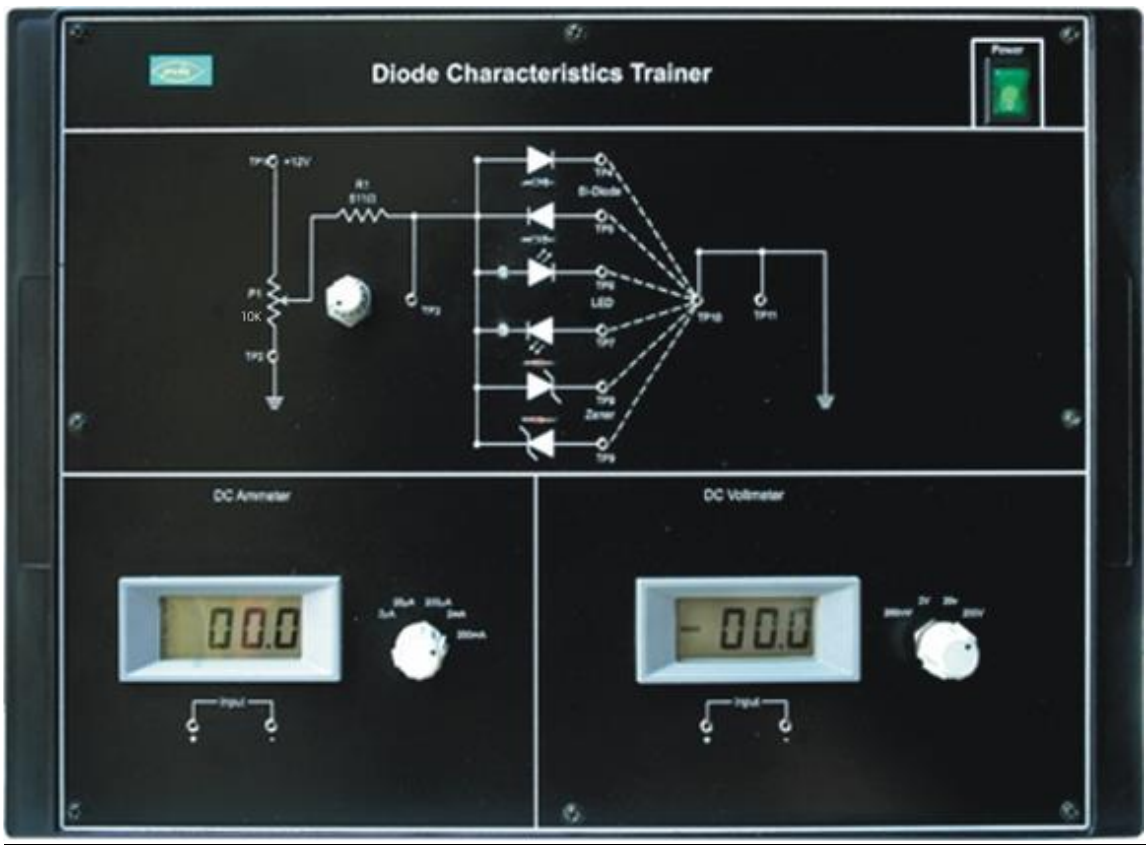


Figure 1. I-V Measurement.

To study the IV characteristic of Si and Ge diode, Zener diode, and LED we have an NV6501 compact, ready to use Diode Characteristics experiment board. This is a standalone circuit board with Si and Ge diode, Zener diode, LED and inbuilt DC power supply and as well as built in Voltmeter and Ammeter. Identify the various components Si diode, Ge diode, Zener diode and LED in diode characteristic circuit board shown in figure 4.



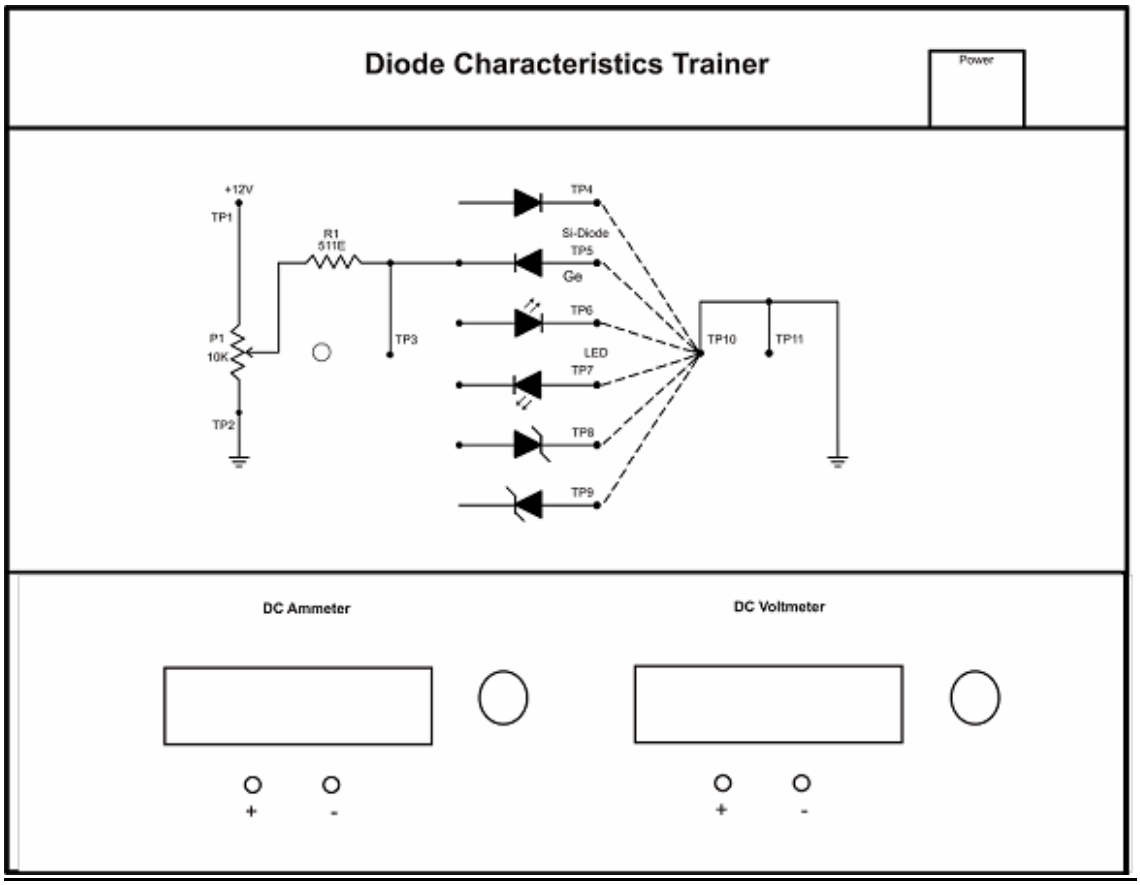
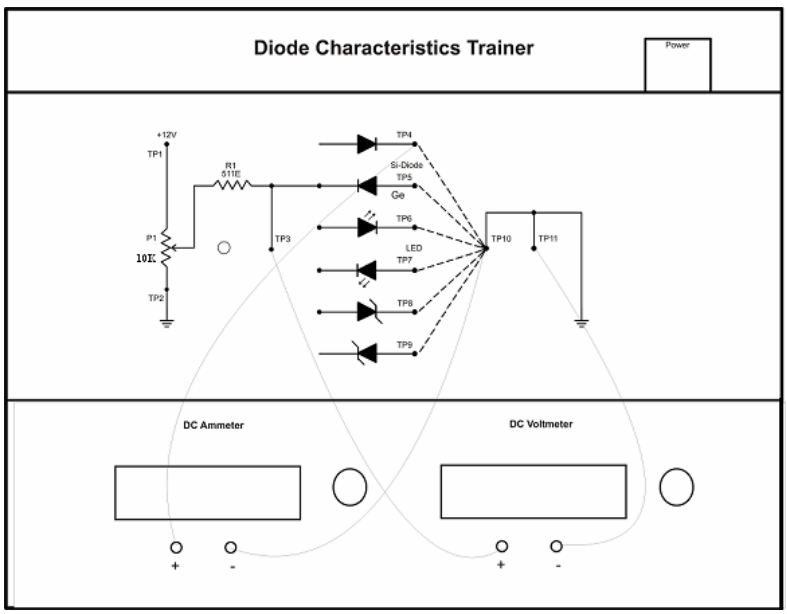


Fig: Diode Characteristics experiment Circuit Board

Procedure

Part 1: For Study of Forward Characteristics of Silicon diode

1. Before switch 'On' the supply rotate potentiometer P1 fully in CCW (counter clockwise direction).



2. Connect Ammeter between TP4 and TP10, to measure diode current ID (mA) & set Ammeter at 200mA range.

3. Connect Voltmeter across TP3 and TP11, to measure diode voltage VD & set Voltmeter at 20V range.

4. Switch 'On' the power supply.

5. Vary the potentiometer P1 so as to increase the value of diode voltage VD from 0 to 1V (0.83V) in steps and measure the corresponding values of diode current ID in mA and note down in the Observation Table 1.

6. Plot a curve between diode voltage VD and diode current ID as shown in figure 3 (First quadrant) using suitable scale, with the help of Observation Table 1. This curve is the required forward characteristics of Si diode.

7. Switch 'Off' the supply.

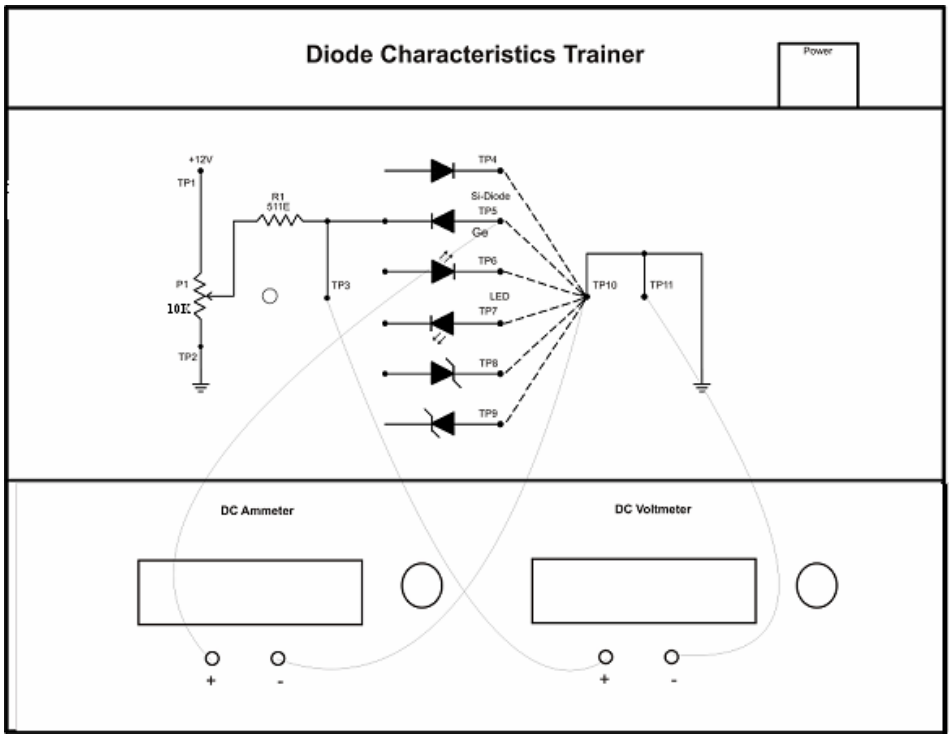
Observation Table 1:

S. no.	Diode Voltage (VD)	Diode current ID (mA)
1	**0.1V**	
2	**0.2V**	
3	**0.3V**	
4	**0.4V**	
5	**0.5V**	
6	**0.6V**	
7	**0.7V**	
8	**0.8V**	
9	**0.9V**	
10	**1.0V**	

Study of Reverse Characteristics of Germanium Diode

Circuit Diagram:

Circuit used to plot Reverse characteristics of Ge diode is shown in figure 29.



Procedure:

1. Before switch 'On' the supply rotate potentiometer P1 fully in CCW (counter clockwise direction).

2. Connect Ammeter between TP5 and TP10, to measure diode current ID (μA) & set Ammeter at 200μA range.

3. Connect Voltmeter across TP3 and TP11, to measure diode voltage VD & set Voltmeter at 20V range.

4. Switch 'On' the power supply.

5. Vary the potentiometer P1 so as to increase the value of diode voltage VD from 0 to maximum in steps and measure the corresponding values of diode current ID in μA and note down in the Observation Table 2.

6. Plot a curve between diode voltage VD and diode current ID as shown in figure 3 (third quadrant) using suitable scale with the help of Observation Table 2. This curve is the required reverse characteristics of Ge diode.

7. Switch 'Off' the supply.

Observation Table 2:

S. no.	Diode Voltage (VD)	Diode current ID (µA)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

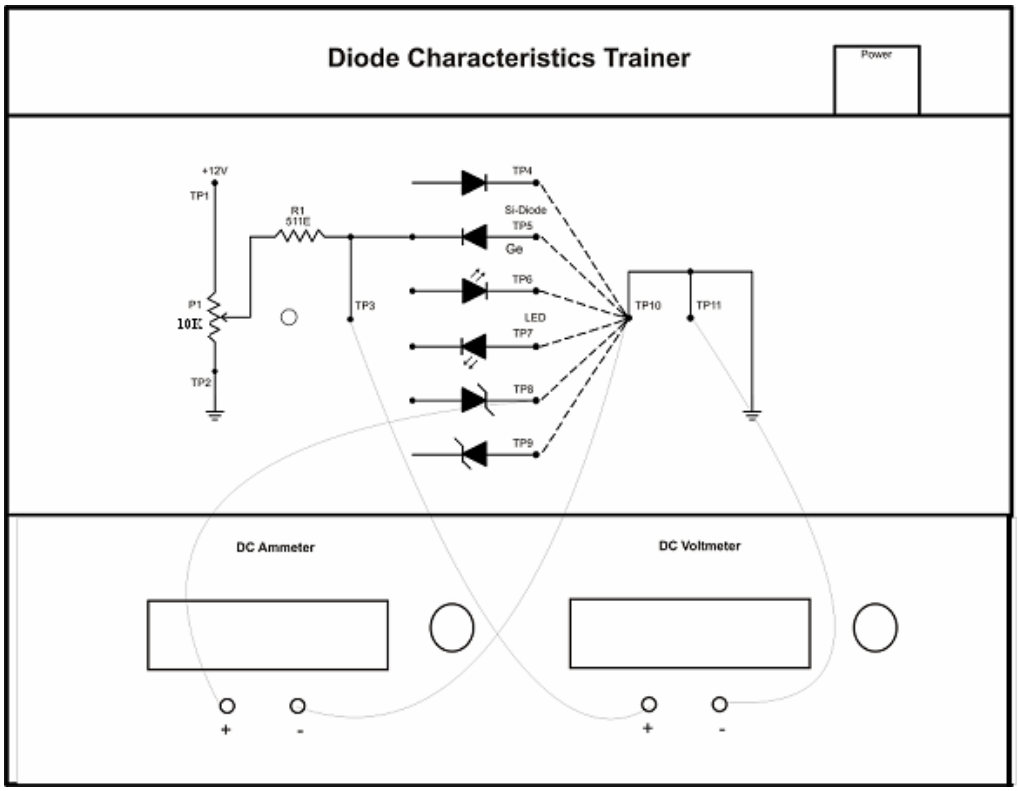
Study of characteristics of Zener diode

1. Forward bias

2. Reverse bias

Circuit Diagram :

Circuit used to plot different characteristics of Zener diode is shown in figure 31.



Procedure:

To plot Forward Characteristics proceed as follows :

1. Rotate potentiometer P1 fully in CCW (counter clockwise direction).

2. Connect Ammeter between TP8 and TP10, to measure diode current ID (mA) & set Ammeter at 200mA range.

3. Connect Voltmeter across TP3 and TP11, to measure diode voltage VD & set Voltmeter at 20V range.

4. Switch 'On' the power supply.

5. Vary the potentiometer P1 so as to increase the value of Zener voltage Vz from zero to 1V in steps and measure the corresponding values of Zener current Iz in mA & note down in the Observation Table 3.

6. Plot a curve between diode voltage Vz and diode current Iz as shown in figure 4 (First quadrant) using suitable scale, with the help of Observation Table 3. This curve is the required Forward Characteristics of Zener diode.

7. Switch 'Off' the supply.

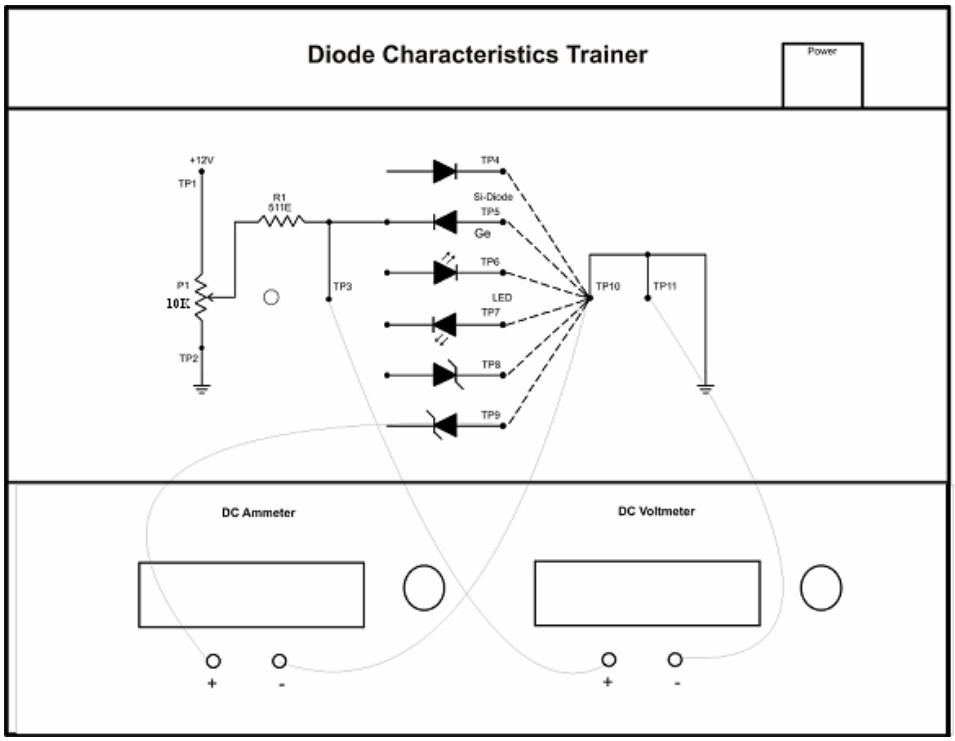
Observation Table 1:

S. no.	Diode Voltage (VZ)	Diode current IZ (mA)
1	0.1V	

2	**0.2V**	
3	**0.3V**	
4	**0.4V**	
5	**0.5V**	
6	**0.6V**	
7	**0.7V**	
8	**0.8V**	
9	**0.9V**	
10	**1.0V**	

To plot Reverse Characteristics of a Zener diode proceed as follows:

1. Rotate potentiometer P1 fully in CCW (counter clockwise direction).



2. Connect Ammeter between TP9 and TP10, to measure diode current ID (mA) & set Ammeter at 200mA range.

3. Connect Voltmeter across TP3 and TP11, to measure diode voltage VD & set Voltmeter at 20V range.

4. Switch 'On' the power supply.

5. Vary the potentiometer P1 so as to increase the value of diode voltage VD from zero to 6.8V in steps and measure the corresponding values of diode current Iz in mA & note down in the Observation Table 4.

6. Plot a curve between diode voltage Vz and diode current Iz as shown in figure 4 (third quadrant) using suitable scale, with the help of Observation Table 4. This curve is the required Reverse Characteristics of Zener diode.

7. Switch 'Off' the supply.

Observation Table 1:

S. no.	Diode Voltage (VZ)	Diode current IZ (mA)
1	1.0 V	
2	2.0 V	
3	3.0 V	
4	4.0 V	
5	5.0 V	
6	6.0 V	
7	7.0 V	
8	8.0 V	

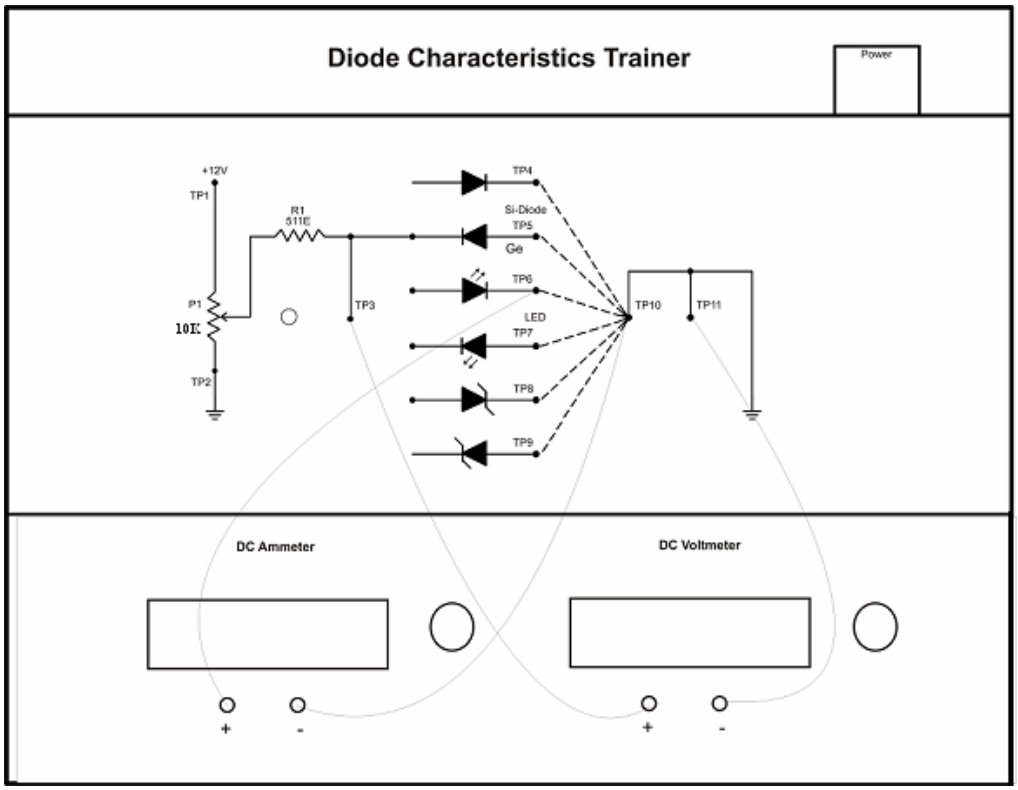
Study of Characteristics of Light Emitting Diode (LED)

1. Forward bias

2. Reverse bias

Circuit Diagram :

Circuit used to plot different characteristics of Light Emitting Diode (LED) is shown in Figure below.



Procedure :

To plot Forward Characteristics proceed as follows :

1. Rotate potentiometer P1 fully in CCW (counter clockwise direction).

2. Connect Ammeter between TP6 and TP10, to measure diode current ID (mA) & set Ammeter at 200mA range.

3. Connect Voltmeter across TP3 and TP11, to measure diode voltage VD & set Voltmeter at 20V range.

4. Switch 'On' the power supply.

5. Vary the potentiometer P1 so as to increase the value of LED voltage VD from zero to maximum in steps and measure the corresponding values of LED current ID in mA & note down in the Observation Table 5.

6. Plot a curve between diode voltage VD and diode current ID as shown in figure 6 (first quadrant) using suitable scale, with the help of Observation Table 5. This curve is the required Forward Characteristics of Light Emitting Diode.

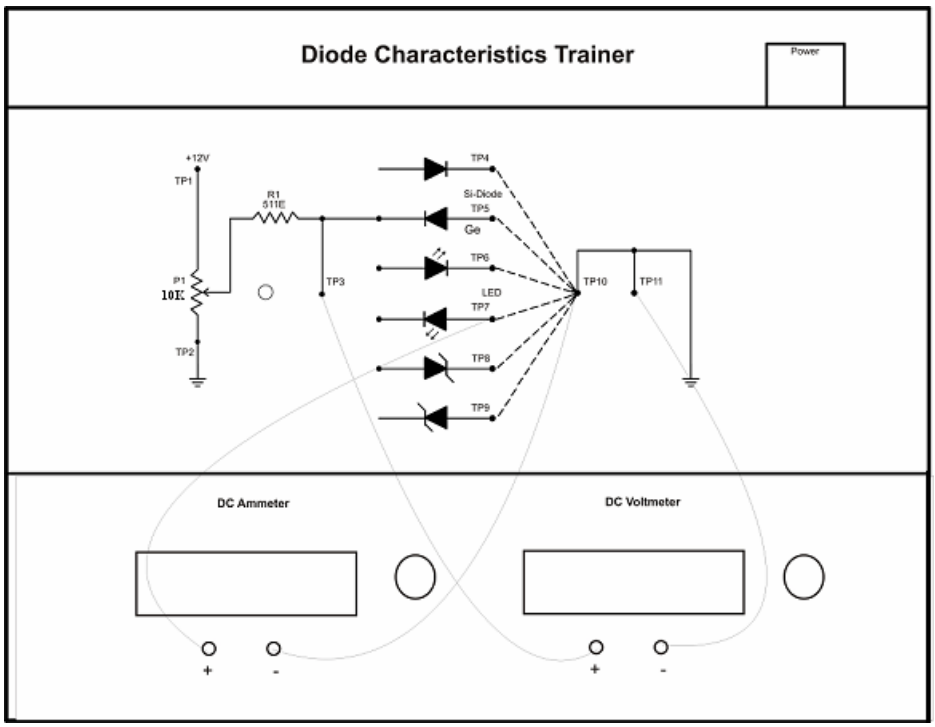
7. Switch 'Off' the supply.

Observation Table 5:

S. no.	Diode Voltage (VD)	Diode current ID (µA)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

To plot Reverse Characteristics proceed as follows :

1. Rotate potentiometer P1 fully in CCW (counter clockwise direction).



2. Connect Ammeter between TP7 and TP10, to measure diode current ID (mA).

3. Connect Voltmeter across TP3 and TP11, to measure diode voltage VD.

4. Switch 'On' the power supply.

5. Vary the potentiometer P1 so as to increase the value of diode voltage VD from zero to maximum in steps and measure the corresponding values of diode current ID in an Observation Table 6.

6. Plot a curve between diode voltage VD and diode current ID as shown in figure 6 (third quadrant) using suitable scale, with the help of Observation Table 6. This curve is the required Reverse Characteristics of Light Emitting Diode.

7. Switch 'Off' the supply.

Observation Table 6:

S. no.	**Diode Voltage (VD)**	**Diode current ID (µA)**
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Results

We plot the readings on I vs V curve and the corresponding graphs look as follows:

Forward bias graph for Si Diode:

Reverse bias graph for Ge Diode:

Forward IV Characteristics for LED:

Reverse Bias characteristics for Zener diode:

Precautions

•If, we just reverse the diode to measure the I-V characteristics, the sudden change might destroy the diode.

•The diode should not be short-circuited. That will allow a flow of huge current which might destroy the diode.

•Current must not pass through it for a very long time. It will then increase the depletion region and develop a fluctuating resistance.

Experiment

AIM:

Study of the hysteresis loop for a given ferromagnetic material on a CRO using a solenoid

Equipment Needed:

CRO, Ferromagnetic Sample, Solenoid, Hysteresis Loop Tracer

Theory:

Hysteresis Loop experiment is useful in understanding the basic concepts and fundamentals of hysteresis loss in feromagnetic substances. The characteristic which are usually used to define the magnetic properties of the substance are coercivity, retentivity, saturation magnetization and hysteresis loss. A precise knowledge of these various magnetic parameters of ferromagnetic substances and ability to determine them accurately are important aspects of magnetic studies.

In general, term “hysteresis” (comes from Greek “hyst´er¨esis”, - lag, delay) means that value describing some physical process is ambiguously dependent on an external parameter and antecedent history of that value must be taken into account. The term was added to the vocabulary of physical science by J. A. Ewing, who defined it as following: “When there are two quantities Mand N such that cyclic variations of N cause cyclic variations of M, then if the changes of M lag behind those of N, we may say that there is hysteresis in the relation of M to N”. One can meet theword “hysteresis” in magnetism and electricity, thermodynamics, where it is always a sign of first order phase transition.

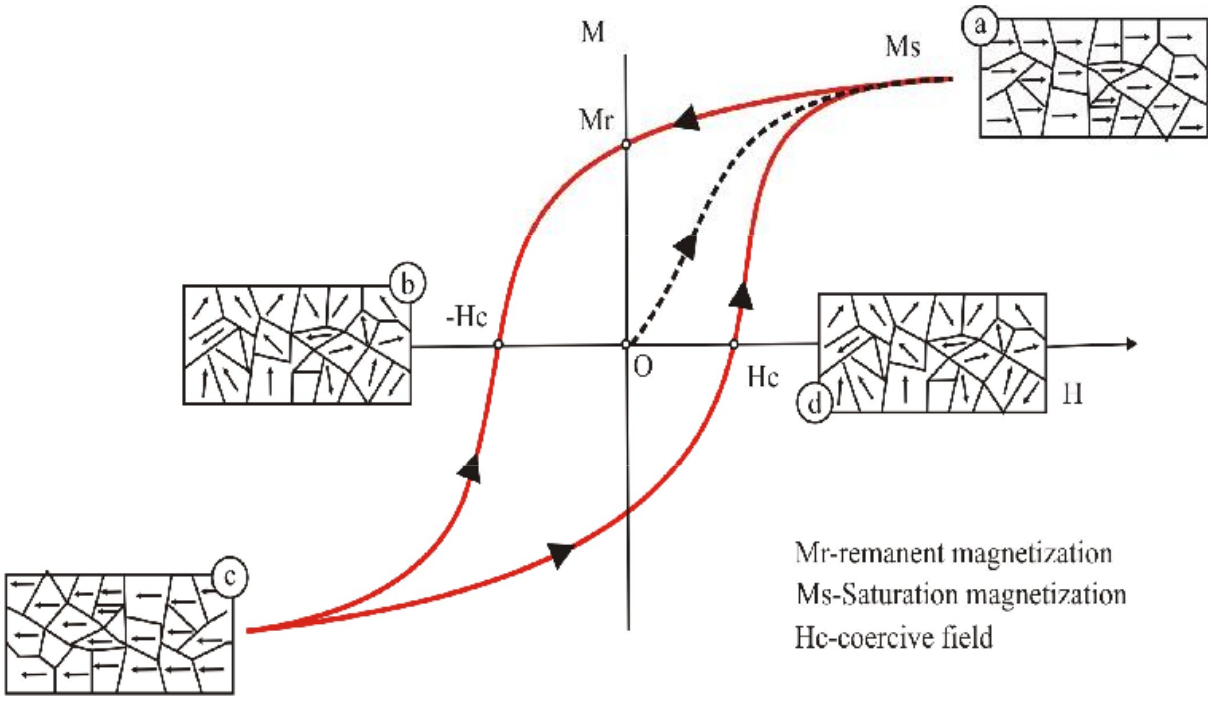
Ferromagnetism:

Iron, nickel, cobalt and some of the rare earths (gadolinium, dysprosium) exhibit a unique magnetic behavior which is called ferromagnetism (iron or ‘ferric’ is the most common and most dramatic example of a ferromagnetic material). Ferromagnetic materials exhibit a long-range ordering phenomenon at the atomic level which causes the atomic magnetic moments to line up parallel with each other in a region called a domain. Within the domain, the magnetization is intense, but in a bulk sample the material will usually be demagnetized because the many domains will be randomly oriented with respect to one another. A small externally imposed magnetic field, say from a solenoid, can cause the magnetic domains to line up with each other. The magnetic flux density in the material will then be increased by a large factor called relative permeability for the material compared to the magnetic flux density in

vacuum, μ0H. All ferromagnets have a maximum temperature where the ferromagnetic property disappears as a result of thermal agitation. This temperature is called the Curie Temperature.

Hysteresis Loop:

When a ferromagnetic material is magnetized in one direction, it does not relax back to zero magnetization, when the imposed magnetizing field is re-moved. In order to bring it back to zero magnetization state by a field in the opposite direction is applied.



The Magnetization 'M' vs Magnetic Field strength 'H' for a ferromagnetic/ferromagnetism

If an alternating magnetic field is applied to the material, its magnetization will trace out a loop called a hysteresis loop (see figure 2). The lack of retraceability of the magnetization curve is the property called hysteresis and it is related to the existence of magnetic domains in the material. Once the magnetic domains are reoriented, it takes some energy to turn them.

(a) Starting at zero the material follows at first a non-linear magnetization curve and reaches the saturation level, when all the magnetic domains are aligned with the direction of a field; when afterwards driving magnetic field drops to zero, the ferromagnetic material retains a considerable degree of magnetization or "remember" the previous state of magnetization;

(b) At this point, when H = 0 a ferromagnet is not fully demagnetized and only the partial domain reorientation happened;

(c) saturation level in the opposite direction of applied field;

(d) In order to demagnetize a ferromagnetic material the strong magnetic field of the opposite direction (called "coercive field, 'Hc') has to be applied. Back again. This property of ferromagnetic materials is useful as a magnetic "memory". Some compositions of ferromagnetic materials will retain an imposed magnetization indefinitely and are useful as "permanent magnets". The magnetic memory aspects of iron and chromium oxides make them useful in audio tape recording and for the magnetic storage of data on computer disks.

Basic relations of Magnetic Hysteresis Theory:

In vacuum the generated magnetic flux density or magnetic induction is proportional to applied

field B:

$B = \mu 0H+J$

Where $\mu 0= 4\pi\times10^{-7}$V s/Am = 1, 26 $\cdot10^{-6}$V s/Am. The unit of the magnetic field is Am and for the magnetic flux density B we have V s/m^2= 1 Tesla.

Magnetic Hysteresis:

If material is present, this equation becomes

$B = \mu r\mu 0H+J$

With μr-relative permeability of the material. The relative permeability of the material is dimensionless and is a pure number characterizing the material. It is useful and conventional to split B into the flux density in vacuum plus the "part of the material" according to

$B = \mu 0 (H + M)$,

where M is magnetization (total magnetic moment) vector that is only material dependent. While excluding B from the equation (3) one can obtain 2

$M = (\mu r− 1) H$

The relative permeability μr is the prime material parameter. It describes the response of a material to a magnetic field.

If a ferromagnetic material is chosen one can observe that a generated magnetic flux density in the material is not proportional to applied field H.

Rather, it reaches a saturation value Bs as the magnetic field H increases. The relative permeability μr of the ferromagnet depends on the magnetic field strength H, and also on the previous magnetic treatment of the ferromagnet. In a demagnetized ferromagnet, the magnetic field strength is

B = 0 T at H = 0 A/m

However, a ferromagnet still retains a residual magnetic flux density B not equal to 0T when H = 0 A/m (remanence) or remembers its previous state. Thus, the hysteresis curve differs from the magnetization curve, which begins at the origin of the coordinate system and can only, be measured for completely demagnetized material.

H = 0 A/m, B = 0 T

The values of magnetic field strength and magnetic induction can be measured indirectly by monitoring the applied current I in the transformer coil and the induced magnetic flux Φ through the core and taking into account

1

2

N H = I, B = Φ

L N A

The relations where N1, N2 are the number of turns in primary and secondary coils respecively, L is the inductance of a coil; A is the cross-section of a ferromagnet. The magnetic flux Φ is calculated as the integral of the voltage as induced in the secondary coil.

Design Principle:

When a cylindrical sample is placed coaxially in a periodically varying magnetic field (say by the

solenoid) the magnetization in the sample also undergoes a periodic variation. This variation can

be picked coil is wound near the central part of the sample. Normally, the pickup coil is wound

near the central part of the sample so that the demagnetization factors involved are ballistic rather

than the magneto metric.

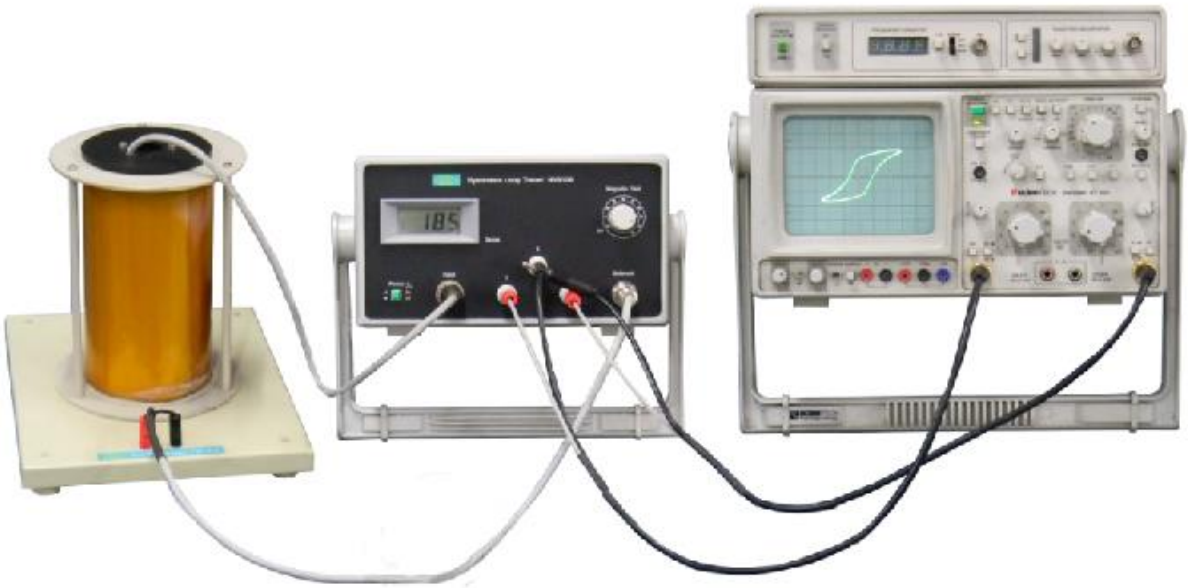
For the uniform field Ha produced, the effective field H acting in the cylindrical sample will be

H = Ha – NM, where M is the magnetization, or

H = Ha –0NJμ , where N is the normalized demagnetization factor including 4π and J is the magnetic polarization defined by

Procedure:

1. Take sample holder and insert a ferromagnetic sample in the lower side



2. Now insert this sample holder in the solenoid.

3. Connect the mains cord to instrument (Hysteresis Loop Tracer) on the back side.

4. Before switch 'On' the Hysteresis Loop Tracer, connect din connector cable of sample holder to the **Input** of the Hysteresis Loop Tracer.

5. Connect solenoid to **Solenoid** socket of Hysteresis Loop Tracer using three pin connector cable.

6. Connect 'Y' terminal of Hysteresis Loop Tracer to CRO 'Y' terminal with the help of BNC to 4 mm connector cable and other terminal of its cable to the 'E' terminal of Hysteresis Loop Tracer.

7. Similarly connect 'X' terminal of Hysteresis Loop Tracer to CRO 'X' terminal with the help of BNC to 4 mm connector cable and other terminal of its cable to the 'E' terminal of Hysteresis Loop Tracer.

Note: Here red terminal of both cables should be connected to 'Y' and 'X' terminals respectively of Hysteresis Loop Tracer and black terminal of both cable should be connected to 'E' terminal to Hysteresis Loop Tracer.

8. Keep CRO in 'XY' mode.

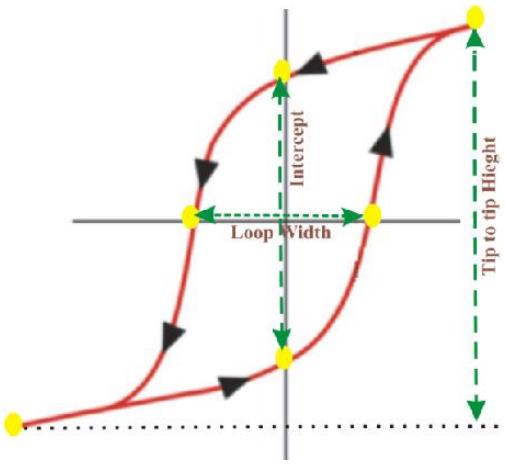
9. After installation of complete setup, Switch 'On' the Hysteresis Loop Tracer and CRO.

10. Adjust the magnetic field intensity with the help of **Magnetic Field** knob of the tracer.

11. Here magnetic field in Gauss will displays on DPM in accordance to the intensity of magnetic field.

12. Now the Hysteresis Loop of the taken sample will be displayed on CRO.

13. Adjust this Hysteresis Loop on the CRO screen using both Volts/Div knobs (X & Y) such that you can read all parameters of this loop easily.



Observations:

Equipment diameter of pickup coil = 3.21 mm

g_x = 100 (Total gain of both amplifier)

g_y = 1 (Gain of amplifier)

Sample = Commercial Nickel (standard)

Length of Sample (C) = 39 mm

Diameter of Sample (a) =1.17 mm

Cross Sectional Area of Sample (As) = πr_1^2 = 1.074

Cross Sectional Area of pickup coil (Ac) = $\pi\ r_2^2$ = 8.088

Therefore, Area ratio

$$\frac{A_s}{A_c} = \frac{1.074}{7.088} = 0.133mm$$

Demagnetizing Factor (N) = C/a = 39/1.17 = 33.33

= 0.0029 (As per Appendix)

Calibration:

By Adjusting N &$\frac{A_s}{A_c}$ as given above the J-H loop width is too small. Thus both are adjusted to three times i.e. 0.399 (0.4) & 0.0087 (near about zero) respectively. This instrument is also calibrated internally i.e. Demagnetization = near about zero & Area Ratio =0.4.

Set Magnetic Field: 200(rms)

e_x = 80 mm

e_x = 8.0 V (If read by applying on Y input of CRO)

For area ratio of unity:

e_x =80/0.4= 200 mm**…….(1)**

e_x =8/0.4= 20 V**……(2)**

Now

$$G_o(rms) = \frac{H_a}{e_x}$$

Where, H_a = rms value of magnetic field = 200 (from the display)

G_0 (*rms*) = 200/200 (from eq. **(1)**)

G_0(*rms*) = 1 G/mm

G_0 *(Peak to Peak)* = 1 × 2√2 = 2.828 G/mm**……(3)**

G_0(*rms*) = 200/20 (from eq. **(2)**)

G_0(*rms*) = 10 G/V

G_0 *(Peak to Peak)* = 10 × 2√2 = 28.2 G/V**……(4)**

Calculation:

Loop Width = …… mm

= ……mm (after dividing by the multiplying factor 3)

Note: Here Loop Width is a distance between both intersection points on horizontal axis (x) in mm which is multiplied by position of X channel's Volt/Div knob.

Tip to Tip Height = …..V

Note: Here Tip to Tip Height is a distance between both peak points of loop on vertical axis (Y) in cm (Division) which is multiplied by position of Y channel's Volt/Div knob.

Intercept = …..V

Note: Here Intercept is a distance between both intersection points on vertical axis (Y) in cm (Division) which is multiplied by position of Y channel's Volt/Div knob.

1. Coercivity:

$$H_c = \frac{G_0 e_x}{\left[\frac{A_s}{A_c} - N\right]}$$

Where, e_x= ½ x Loop Width

2. Saturation Magnetization:

$$\mu_s = \frac{J_s}{4\Pi}$$

Where,

$$J_s = \frac{G_0 \mu_0 g_x \left(e_y\right)_s}{g_y \left[\frac{A_s}{A_c} - N\right]}$$

$(e_y)_s$ = ½ × Tip to Tip height

3. Retentivity:

$$\mu_r = \frac{J_r}{4\Pi}$$

Where,

$$J_r = \frac{G_0 \mu_0 g_x (e_x)_r}{g_y \left[\frac{A_s}{A_c} - N\right]}$$

$(e_y)_r$ = ½ x Intercept

Results:

Sample	Coercivity	Saturation Magnetization	Retentivity
Commercial Nickel	……Oe	……Gauss	……Gauss
Hard Steel	……Oe	……Gauss	……Gauss
Soft Iron	……Oe	……Gauss	……Gauss

An Example Calculation

Loop Width = **30** mm

= **10** mm (after dividing by the multiplying factor 3)

Tip to Tip Height = 3.6 V

Intercept = **2.8** V

1. Coercivity:

$$H_c = \frac{G_0 e_x}{\left[\frac{A_s}{A_c} - N\right]}$$

Where,

e_x = ½ x Loop Width = ½ x 10 = 5 mm

G_0= 2.828 G/mm (from eq. **(3)**)

$$\frac{A_s}{A_c} = 0.133mm$$

N = 0.0029

Now

$$H_c = \frac{2.825 \times 5}{[0.133 - 0.0029]}$$

H_c = 108.68

2. Saturation Magnetization:

$$\mu_s = \frac{J_s}{4\Pi}$$

Where,

$$J_s = \frac{G_0 \mu_0 g_x (e_y)_s}{g_y \left[\frac{A_s}{A_c} - N\right]}$$

$(e_y)_s$ = ½ × Tip to Tip height

g_y = 1

g_x = 100

μ_0 = 1

$$\frac{A_s}{A_c} = 0.133mm$$

N = 0.0029 (Permeability of free space)

$(e_y)_s$ = ½ × Tip to Tip Height = 3.6/2 = 1.8 V

$$J_s = \frac{2.82 \times 1 \times 100 \times 1.8}{1 \times [0.133 - 0.0029]}$$

$$J_s = 39016.14$$

Now

$$\mu_S = \frac{39016.14}{4 \times 3.14}$$

$$\mu_S = 3.1\ K\ gauss$$

3. Retentivity:

$$\mu_r = \frac{J_r}{4\Pi}$$

Where,

$$J_r = \frac{G_0 \mu_0 g_x (e_x)_r}{g_y \left[\frac{A_s}{A_c} - N\right]}$$

$(e_y)_r$ = ½ x Intercept

$g_y = 1$

$g_x = 100$

$\frac{A_s}{A_c} = 0.133mm$

N = 0.0029 (Permeability of free space)

$(e_y)_r$ = ½ x Intercept = 2.8/2 = 1.4 V

$$J_r = \frac{28.2 \times 1 \times 100 \times 1.4}{1 \times [0.133 - 0.0029]}$$

$$J_r = 303445.8$$

Now

$$\mu_r = \frac{303445.8}{4 \times 3.14}$$

$$\mu_r = 2.4\ K\ gauss$$

Note: The above observation and calculation are given as a typical example.

Appendix

Demagnetization factors for ellipsoids of revolution for prolate spheroids, c is the polar axis.

C/a	$N_c/4$	C/a	$N_c/4$	C/a	$N_c/4$
1.0	0.333 333	4.0	0.075 4.7	20	0.006 749
1.1	0.308 285	4.1	0.072 990	21	0.006 230
1.2	0.286 128	4.2	0.070 693	22	0.005 771
1.3	0.266 420	4.3	0.068 509	23	0.005 363
1.4	0.248 803	4.4	0.066 431	24	0.004 998
1.5	0.232 981	4.5	0.064 450	25	0.004 671
1.6	0.218 713	4.6	0.062 562	30	0.003 444
1.7	0.205 794	4.7	0.060 760	35	0.002 655
1.8	0.194 056	4.8	0.059 039	40	0.002 116
1.9	0.183 353	4.9	0.057 394	45	0.001 730
2.0	0.173 564	5.0	0.050 821	50	0.001 443
2.1	0.164 585	5.5	0.048 890	60	0.001 053
2.1	0.156 326	6.0	0.043 230	70	0.000 805
2.3	0.148 710	6.5	0.038 541	80	0.000 637

2.4	0.141 669	7.0	0.034 609	90	0.000 518
2.5	0.135 146	7.5	0.031 275	100	0.000 430
2.6	0.129 090	8.0	0.028 421	110	0.000363
2.7	0.123 455	7.5	0.025 958	120	0.000311
2.8	0.118 203	9.0	0.023 816	130	0.000270
2.9	0.113 298	9.5	0.021 939	140	0.000236
3.0	0.108 709	10	0.020 286	150	0.000 209
3.1	0.104 410	11	0.017 515	200	0.000125
3.2	0.100 376	12	0.015 297	250	0.000083
3.3	0.096 584	13	0.013 490	300	0.000060
3.4	0.093 015	14	0.011 997	350	0.000045
3.5	0.089 651	15	0.010 749	400	0.000 036
3.6	0.086 477	16	0.009 692	500	0.000024
3.7	0.083 478	17	0.0008 790	600	0.000017
3.8	0.080 641	18	0.0018 013	700	0.000013
3.9	0.077 954	19	0.0007 339	800	0.000010