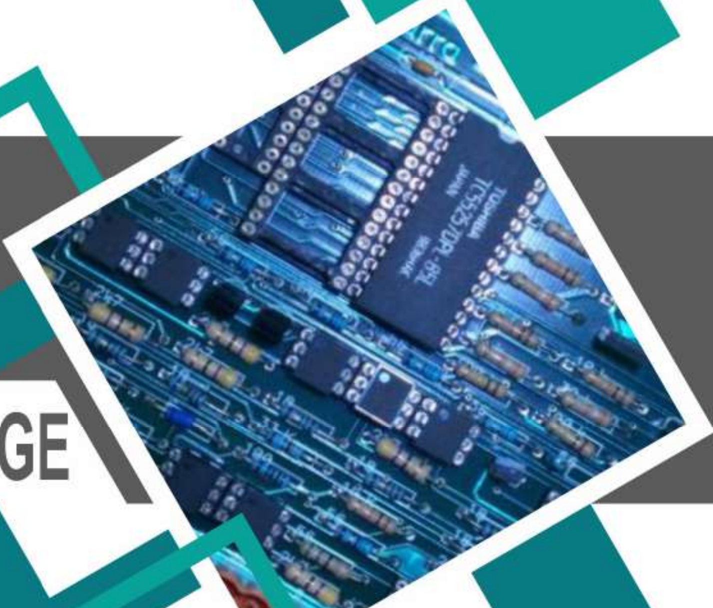
M.Sc. PHYSICS LAB MANUAL

3rd & 4th Semester



Prepared By

Dept. of Pure & Applied Science

Physics

MIDNAPORE CITY COLLEGE

Course No: PHS 396A: Solid State Special Lab

Credit: 4.

1. Study of Hall effect with variation of temperature.

❖ Objective

1) To study Hall Coefficient of semiconductor at room temperature
2) To study the variation of Hall coefficient with temperature.

❖ Theory

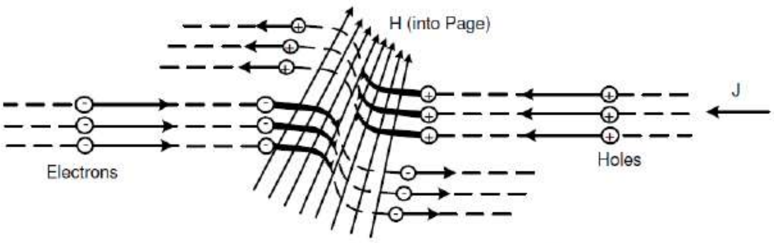


Fig. 1 Carrier separation due to a magnetic field

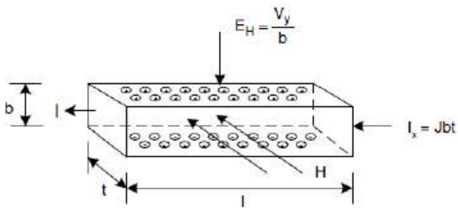


Fig. 2 Sample for studying Hall Effect

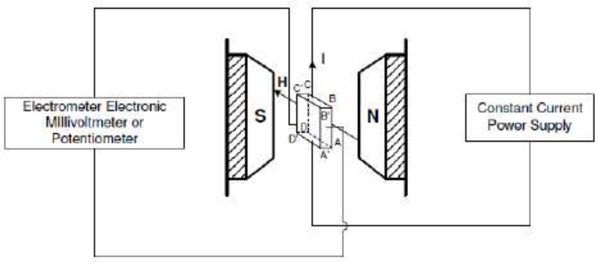


Fig. 3

Conductivity measurements in semiconductors cannot reveal whether one or both types of carriers are present, nor distinguish between them. However, this information can be obtained from Hall Effect measurements, which are a basic tool for the determination of mobilities. The effect was discovered by E.H. Hall in 1879.

Consider a simple crystal mounted as in the Fig. 4, with a magnetic field H in the z direction perpendicular to contacts 1, 2 and 3, 4. If current is flowing through the crystal in the x direction (by application of a voltage V_x between contacts 1 and 2), a voltage will appear across contacts 3, 4 in the y- direction. It is easy to calculate this (Hall) voltage if it is assumed that all carriers have the same drift velocity. We will do this in two steps: (a) by assuming that carriers of only one type are present, and (b) by assuming that carriers of both types are present.

a) One type of carrier:

The magnetic force on the carriers is Fm = e Em = e (v × H) and it is compensated by the force Fh due to the Hall field EH , FH = e EH = Fm . As v is along the x- axis and H along the z-axis, the

electric field E_m is along the y-axis and is given by E_m = vH = $\mu E_x H$ where μ is the carrier mobility given by v = μE_x and E_x is the applied electric field along the x-axis. This electric field is related to the current density and conductivity, $\sigma E_x = J_x$. The Hall coefficient R_H is defined as

$$|R_H| = \frac{E_m}{J_x H} = \frac{\mu E_x}{J_x} = \frac{\mu}{\sigma} = \frac{1}{ne} \tag{1}$$

$$\mu = R_H \sigma , \tag{2}$$

We have used the relation J = nev. Hence for fixed magnetic field and fixed input current, the Hall voltage is proportional to 1/n. It follows that
providing an experimental measurement of the mobility. R_H is expressed in cm^3 $coulomb^{-1}$. Experimentally the coefficient is given by
where b and t are respectively the width and the thickness of the sample. In case the voltage across the input is

$$R_H = \frac{V_y b}{(I_X / bt) H} = \frac{V_y t}{I_X H}, \tag{3}$$

kept constant, it is convenient to define the Hall angle as the ratio of applied and measured voltages:

$$\phi = \frac{V_y}{V_x} = \frac{E_m b}{E_x l} = \mu \frac{b}{l} H \tag{4}$$

where l is the length of the crystal. The Hall angle is thus proportional to the mobility.

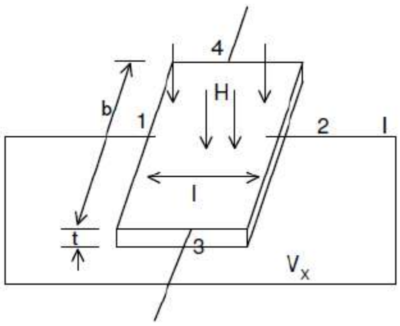


Fig. 4 Schematic arrangement for the measurement of Hall Effect of a crystal

a) Two types of carriers:

Now it is important to recognize that for the same electric field E_x, the Hall voltage for p carriers (holes)

$$e(v_y^{+} p - v_y^{-} n) = 0$$

will have opposite sign from that for n carriers (electrons). (That is, the Hall coefficient R has a different sign.) Thus, the Hall field E_y will not be able to compensate for the magnetic force on both types of carriers and there will be a transverse motion of carriers; however, the net transverse transfer of charge will remain zero since there is no current through the 3, 4 contacts; this statement is expressed as

While

where the mobility is always a positive number; however, v_x has the opposite sign from v_x . It is given by

where is mean time between collisions and m* is the effective of the carriers. Now for holes and electrons, we

$$v_y = \frac{s}{\tau} = \left(\frac{1}{2}\frac{F}{m^*}\tau^2\right)\frac{1}{\tau} ,$$

$$\vec{F}^+ = e[(\vec{v}_x{}^+ \times \vec{H}) - \vec{E}_H]$$

$$\vec{F}^- = -e[(\vec{v}_X{}^- \times \vec{H}) - \vec{E}_H]$$

have

If m_h and m_e are effective masses for holes and electrons, respectively, we get

Since the mobilities $_h$ and $_e$ are not constants but functions of T, the Hall coefficient given by Eq. 6 is

$$v_y{}^+ = \frac{1}{2}\frac{e}{m_h}\tau[(\mu^+ E_x H) - E_H] = \mu^+(\mu^+ E_x H - E_H)$$

$$v_y{}^- = \frac{1}{2}\frac{e}{m_e}\tau[(\mu^- E_x H) - E_H] = \mu^-(\mu^- E_x H + E_H)$$

and

or

$$E_H = E_x H \frac{(\mu_h{}^2 p - \mu_e{}^2 n)}{\mu_h p + \mu_e n} , \qquad (5)$$

and for the Hall coefficient R_H

$$R_H = \frac{E_H}{J_x H} = \frac{E_H}{\sigma E_x H} = \frac{\mu_h{}^2 p - \mu_e{}^2 n}{e(\mu_h p + \mu_e n)^2} \qquad (6)$$

Equation 6 correctly reduces to Eq. 1 when only one type of carrier is present.

also a function of T and it may become zero and even change sign. In general $\mu_e > \mu_h$ so that inversion may happen only if $p > n$; thus ***"Hall coefficient inversion" is characteristic of only "p-type" semiconductors***.

At the point of zero Hall Coefficient, it is possible to determine the ratio of mobilities μ_e/μ_h in a simple manner.

EXPERIMENTAL TECHNIQUE:

(a) Experimental consideration relevant to all measurements on semiconductors

1. Soldered probe contacts, though very much desirable may disturb the current flow (shorting out part of the sample). Soldering directly to the body of the sample can affect the sample properties due to heat and by contamination unless care is taken. These problems can be avoided by using pressure contacts as in the present set-up. The principal drawback of this type of contacts is that they may be noisy. This problem can, however, be managed by keeping the contacts clean and firm.
2. The current through the sample should not be large enough to cause heating. A further precaution is necessary to prevent 'injecting effect' from affecting the measurement. Even

good contacts to germanium for example, may have this effect. This can be minimized by keeping the voltage drop at the contacts low. If the surface near the contacts is rough and the electric flow in the crystal is low, these injected carriers will recombine before reaching the measuring probes.

(b) Experimental consideration with the measurements of Hall coefficient.

1. The Hall Probe must be rotated in the field until the position of maximum voltage is reached. This is the position when direction of current in the probe and magnetic field would be perpendicular to each other.
2. The resistance of the sample changes when the magnetic field is turned on. This phenomena called magneto-resistance is due to the fact that the drift velocity of all carriers is not the same, with magnetic field on, the Hall voltage compensates exactly the Lorentz force for carriers with average velocity. Slower carriers will be over compensated and faster ones under compensated, resulting in trajectories that are not along the applied external field. This results in effective decrease of the mean free path and hence an increase in resistivity.

In general, the resistance of the sample is very high and the Hall Voltages are very low. This means that practically there is hardly any current - not more than few micro amperes. Therefore, the Hall Voltage should only be measured with a high input impedance (□1M) devices such as electrometer, electronic millivoltmeters or good potentiometers preferably with lamp and scale arrangements.

Although the dimensions of the crystal do not appear in the formula except the thickness, but the theory assumes that all the carriers are moving only lengthwise. Practically it has been found that a closer to ideal situation may be obtained if the length may be taken three times the width of the crystal.

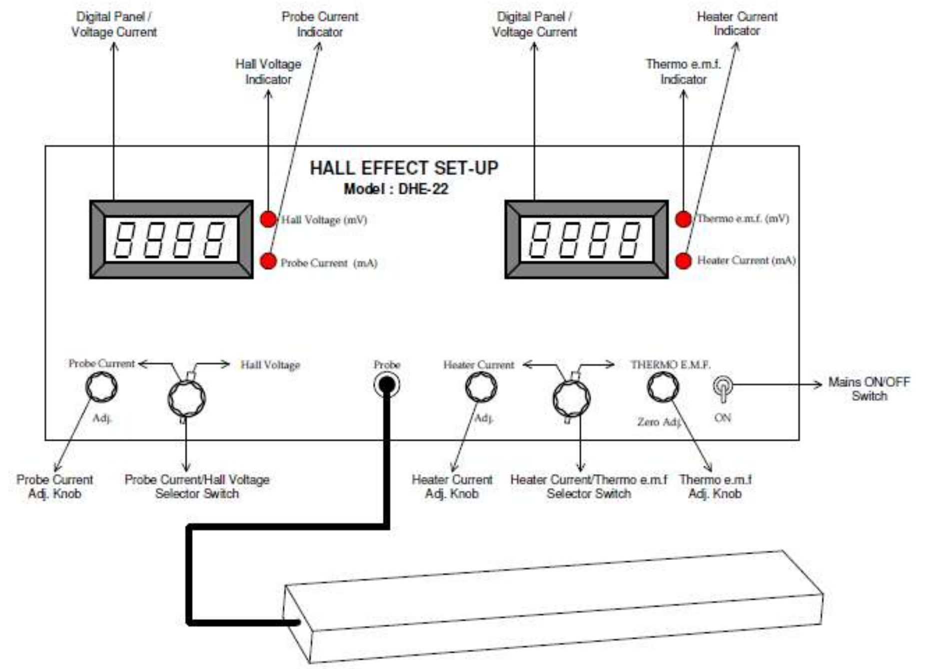


Fig. 5 : Panel Diagram of the Hall effect set up

Apparatus :

1. Hall probe (Ge:p type, n-type)
2. Oven
3. Temperature sensor
4. Hall Effect Set-up, Model : DHE-22
5. Electromagnet, EMU-50V
6. Constant Current Power Supply, DPS-50
7. Digital Gaussmeter, DGM-102

1. HALL PROBE (GE: p-& n-TYPE)

Ge single crystal with four spring type pressure contact is mounted on a glass-epoxy strips. Four leads are provided for connections with the probe current and Hall voltage measuring devices.

2. OVEN

It is a small oven which could be easily mounted over the crystal or removed if required.

Specifications

Size : 35 x 25 x 5 mm (internal size)

Temperature Range : Ambient to 100°CPower requirement : 12W

3. TEMPERATURE SENSOR

Temperature is measured with Cromel-Alumel thermocouple with its junction at adistance of 1 mm from the crystal

4. HALL EFFECT SET-UP, MODEL : DHE-22

The set-up, DHE-22 consists of two sub set-ups, each consisting of further two units.

(i) Measurement of Probe Current & Hall Voltage

This unit consists of a digital millivoltmeter and constant current power supply. The Hall voltage and probe current can be read on the same digital panel meter through a selector switch.

(a) Digital Millivoltmeter

Intersil 3½ digit single chip ICL 7107 have been used. Since the use of internal reference causes the degradation in performance due to internal heating an external reference have **been used. Digital voltmeter is much more convenient to use in Hall Experiment, because the input voltage of either polarity can be measured.**

Specifications

Range : 0-200mV (100V minimum)

Accuracy : 0.1% of reading 1 digit

(b) Constant Current Power Supply

This power supply, specially designed for Hall Probe, provides 100% protection against crystal burn-out due to excessive current. The supply is a highly regulated and practically ripple free dc source.

Specifications

Current : 0-20mA Resolution : 10□A

Accuracy : □0.2% of the reading □1 digit Load regulated : 0.03% for 0 to full load Line regulation : 0.05% for 10% variationInput Supply : 220VAC □10%

(i) Measurement of Thermo emf and Heater current

The unit consists of a digital millivoltmeter and constant current power supply. The thermo emf of thermocouple and heater current can be read on the same DPM through a selector switch.

(a) Digital Millivoltmeter

Intersil 3½ digit single chip ICL 7107 have been used. Since the use of internal reference causes the degradation in performance due to internal heating an external reference have been used. Digital Voltmeter is much more convenient to use, because the input voltage of either polarity can be measured.

Specification

Range: 0 - 20 mV

Resolution: 10 □V equivalent to 0.25ºC in terms of thermo emf Accuracy: □0.1% of reading □ 1 digit

(b) Constant Current Power Supply

The supply is highly regulated and practical ripple free source.

Specifications

Current: 0 - 1A

Accuracy: □0.2% of the reading □ 1 digit Line regulation: 0.1% for 10% variation Load regulation: 0.1% for 0 to full load Input Supply : 220VAC □10%

CALIBRATION TABLE FOR CHROMEL-ALUMEL

ºC	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	0.00	0.04	0.08	0.12	0.16	0.20	0.24	0.28	0.32	0.36
10	0.40	0.44	0.48	0.52	0.56	0.60	0.64	0.68	0.72	0.76
20	0.80	0.84	0.88	0.92	0.96	1.00	1.04	1.08	1.12	1.16
30	1.20	1.24	1.28	1.32	1.36	1.40	1.44	1.49	1.53	1.57
40	1.61	1.65	1.69	1.73	1.77	1.81	1.85	1.90	1.94	1.98
50	2.02	2.06	2.10	2.14	2.18	2.23	2.27	2.31	2.35	2.39
60	2.43	2.47	2.51	2.56	2.60	2.64	2.68	2.72	2.76	2.80
70	2.85	2.89	2.93	2.97	3.01	3.05	3.10	3.14	3.18	3.22
80	3.26	3.30	3.35	3.39	3.43	3.47	3.51	3.56	3.60	3.64
90	3.68	3.72	3.76	3.81	3.85	3.89	3.93	3.97	4.01	4.06
100	4.10	4.14	4.18	4.22	4.26	4.31	4.35	4.39	4.43	4.47
110	4.51	4.55	4.60	4.64	4.68	4.72	4.76	4.80	4.84	4.88

PROCEDURE

1. **Calibration of applied magnetic field:** Place the gaussmeter in between electromagnets and arrange the set up as shown in Fig. 6. For no current in the coils, use the "ZERO ADJ." knob to bring the magnetic field to 0, if required. Switch ON the constant current power supply. Gradually increase the current to the coils in suitable steps and record the magnetic field as displayed by the gaussmeter. Plot a calibration curve for current ~ magnetic field. Use this plot later to determine magnetic field for any given current to the electromagnets.
2. Remove the gaussmeter carefully and replace it with the sample hall probe (p- or n- type Ge) connected to the Hall effect set up as shown in Fig. 7.

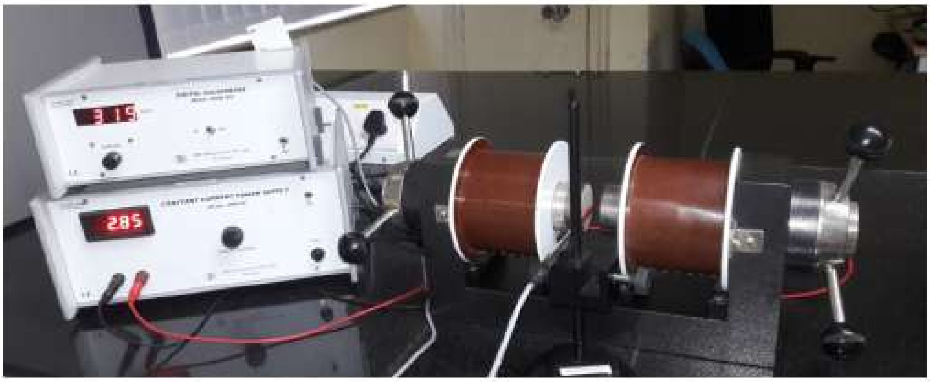


Fig. 6: Set up for calibration of applied magnetic field

Fig. 7: Set up for Hall voltage measurement

3. Switch 'ON' the Hall Effect set-up. Set the probe current at 0 and turn the display to voltage side. There may be some voltage reading due to imperfect alignment of the four contacts of the Hall Probe. This is generally known as the 'Zero field Potential'. It should be adjusted to a minimum possible value and later it should be subtracted from the observed Hall Voltage values.
4. **Measurement of Hall voltage ~ Probe current at room temperature (For both p- and n-type):** Note the ambient temperature. Switch on the electromagnet power supply and adjust the current to any desired value. Rotate the Hall probe till it become perpendicular to magnetic field. Hall voltage will be maximum in this adjustment.
5. Measure Hall voltage. Find the magnetic field corresponding to the current value using calibration plot. Calculate Hall coefficient at room temperature.
6. **Measurement of Hall voltage ~ Temperature for fixed probe current (For p-Ge):** Repeat step 4 keeping p-type Ge Hall probe in between the electromagnet. Determine the magnetic field.
7. Set the probe current at about 4 mA. Gradually vary the heater current up to say about 1A. After every new setting of heater current, wait for about 7-8 minutes for the temperature to stabilize. This would be indicated by a stable thermo e.m.f. also. Note down the temperature from calibration table.

Record the Hall voltage reading at the set temperature. Then switch off the constant current power supply of the electromagnet. Note down the off-set voltage at residual magnetic field and subtract it from the Hall voltage. This is very important.

9. There is no need to gradually increase/decrease the magnetic field. Just switch 'OFF' the supply for off-set voltage and switch 'ON' for the next reading.
10. Change of sign of Hall voltage on heating would occur for p-type sample only. This is explained in the Manual. There is no need to take further readings after the change of sign.
11. Allow about 10 minutes time for the thermal stabilization of the DHE-22 every time the experiment is to be performed.
12. Thermo emf (mV) reading if any at ambient temperature i.e. without heater current should be subtracted from the thermo emf reading to get the corresponding correct temperature from the calibration table provided with the set-up. It is assumed that the thermo-emf of the chromel-alumel thermocouple used with the heating arrangement varies linearly with the temperature difference between the two junctions of the thermocouple.
13. Calculate hall coefficient for each Hall voltage and plot it as a function of temperature.

Optional measurements:

14. Similarly, measurement of Hall voltage ~ Temperature can be performed for n-Ge at a fixed probe current.
15. Additionally, one can also vary magnetic field and record corresponding hall voltage at a given temperature. Hall coefficient can be calculated from a suitable plot.

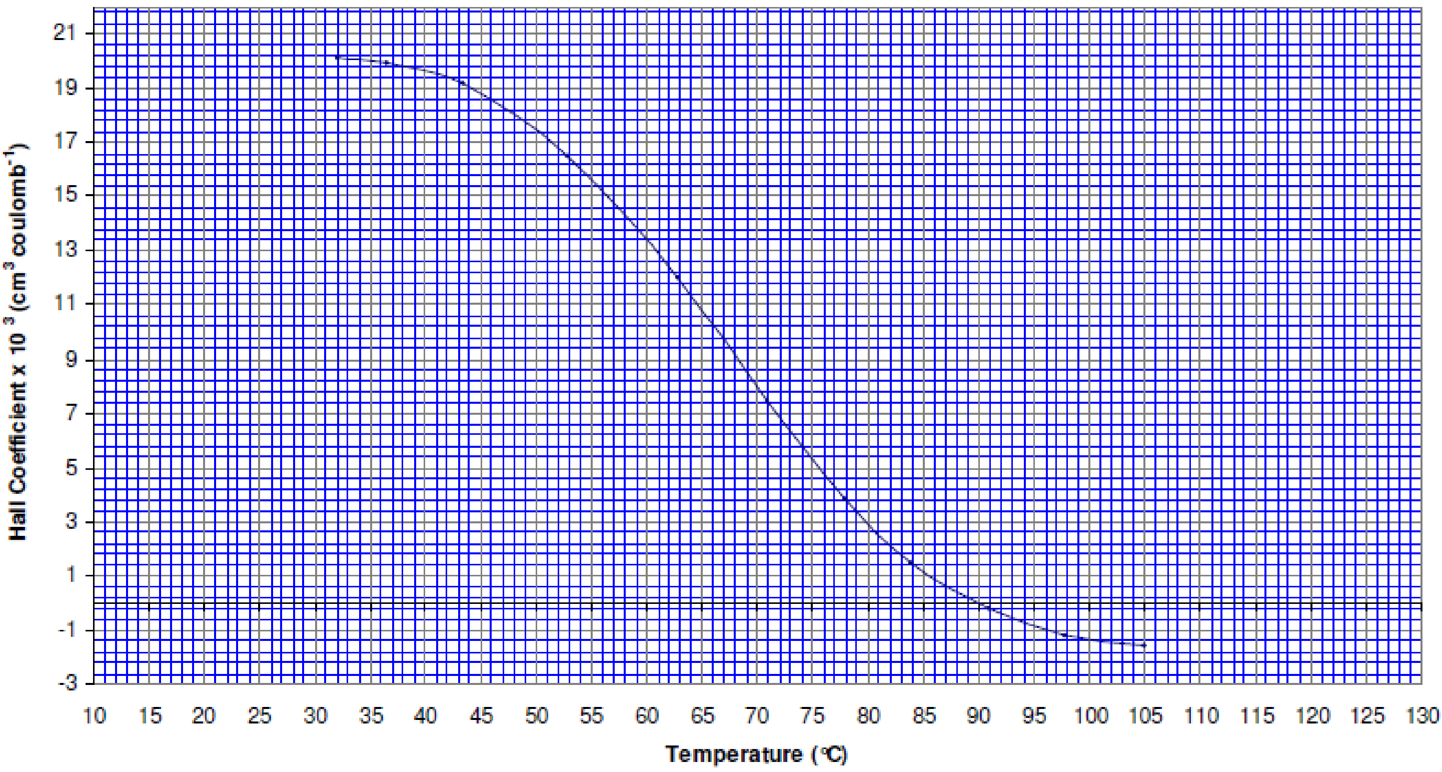


Fig. 8: Sample graph showing Hall coefficient ~ Temperature for p-Ge

Note : Since Hall voltage at residual magnetic field form the part of Offset Voltage, the magnetic field for Hall Coefficient calculation would be = 3.13 - 0.13 = 3.00 KG

Graph: Variation of Hall Coefficient with temperature is shown in the sample graph

Formula used for calculation of Hall Coefficient (R)

$$R = \frac{V_y t}{I H}$$

where, V_y = Hall voltage

t = Thickness of the sample I = Probe current

H = Magnetic field

S.No.	Heater current (mA)	Thermo. e.m.f. (mV)	Temp (^oC)	Hall Voltage (mV)	Off-set voltage at residual (mV)	Corrected Hall Voltage (mV)	Hall Coefficient ($cm^3.coulomb^{-1}$)
1	0	0.00	17.0	54.6	-0.8	55.4	23.08
2	200	0.09	19.3	54.3	-0.9	55.2	23.00
3	300	0.29	24.3	54.8	0.29	54.5	22.71
4	400	0.59	31.8	53.1	-1.2	54.3	22.63
5	500	0.98	41.5	56.6	2.8	53.8	22.42
6	550	1.27	48.8	54.7	3.2	51.5	21.46
7	600	1.52	54.8	49.9	2.6	47.3	19.71
8	650	1.77	61.0	41.9	2.0	39.9	16.63
9	700	2.02	67.0	22.0	-8.7	30.7	12.79
10	750	2.25	72.0	14.4	-7.6	22.0	9.17
11	800	2.53	79.5	5.0	-7.4	12.4	5.17
12	850	2.82	86.5	-4.8	-8.6	3.8	1.58
13	900	3.05	92.0	-6.3	-6.7	-0.4	-0.17
14	950	3.54	100.8	-7.9	-5.2	-2.7	-1.13
15	1000	3.71	107.8	-7.8	-4.2	-3.6	-1.50

Note : Since Hall voltage at residual magnetic field form the part of Offset Voltage, the magneticfield for Hall Coefficient calculation would be = 3.13 - 0.13 = 3.00 KG

Graph: Variation of Hall Coefficient with temperature is shown in the sample graph

Formula used for calculation of Hall Coefficient (R)

$$R = \frac{V_y\, t}{I\, H}$$

where, V_y = Hall voltage
t = Thickness of the sample
I = Probe current
H = Magnetic field

Calculations:

(a) Calculate charge carrier density from the relation

$$R = \frac{1}{ne} \Rightarrow n = \frac{1}{Re}$$

(b) Calculate carrier mobility, using, the formula

$$\mu_n \text{ (or } \mu_p) = R\sigma$$

using the specified value of resistivity ($1/\sigma$) given by the supplier or obtained by some other method (Four Probe Method).

2. Study of Dielectric Constant and Curie Temperature Measurement of Ferroelectric Ceramics

INTRODUCTION

Research in the area of Ferroelectrics is driven by the market potential of next generation memories and transducers. Thin films of ferroelectrics and dielectrics are rapidly emerging in the field of MEMS applications. Ultrasonic micro-motors utilizing PZT thin films and pyroelectric sensors using micro-machined structures have been fabricated. MEMS are finding growing aplication in accelerometers for air bag deployment in cars, micro-motors and pumps, micro heart valves, which have reached the commercial level of exploitation in compact medical, automotive, and space applications. Extremely sensitive sensors and actuators based on thin film and bulk will revolutionize every walk of our life with Hi-Tech gadgets based on ferroelectrics. Wide spread use of such sensors and actuators have made Hubble telescope a great success story. New bulk ferroelectric and their composites are the key components for the defence of our air space, the long coastline and deep oceans.

The quest of human beings for developing better and more efficient materials is never ending. Material Scinece has played a vital role in the development of society. Characterization is an important step in the development of different types of new materials. This experiment is aimed to expose the young students to Dielectric and Curie Temperature Measurement techinque for Ferroelectric Ceramics.

Dielectric or electrical insulating materials are understood as the materials in which electrostatic fileds can persist for a long time. These materials offer a very high resisitance to the passage of electric current under the action of the applied *direct-current* voltage and therefore sharply differ in their basic electrical properties from conductive materials. Layers of such substances are commonly inserted into capacitors to improve their performance, and the term *dielectric* refers specifically to this application.

The use of a dielectric in a capacitor presents several advantages. The simplest of these is that the conducting plates can be placed very close to one another without risk of contact. Also, if subjected to a very high electric field, any substance will ionize and become a conductor. Dielectrics are more resistant to ionization than air, so a capacitor containing a dielectric can be subjected to a higher voltage. Also, dielectrics increase the capacitance of the capacitor. An electric field polarizes the molecules of the dielectric (Figure-1), producing concentrations of charge on its surfaces that create an electric field opposed (antiparallel) to that of the capacitor. Thus, a given amount of charge produces a weaker field between the plates than it would without the dielectric, which reduces the electric potential. Considered in reverse, this argument means that, with a dielectric, a given electric potential causes the capacitor to accumulate a larger charge.

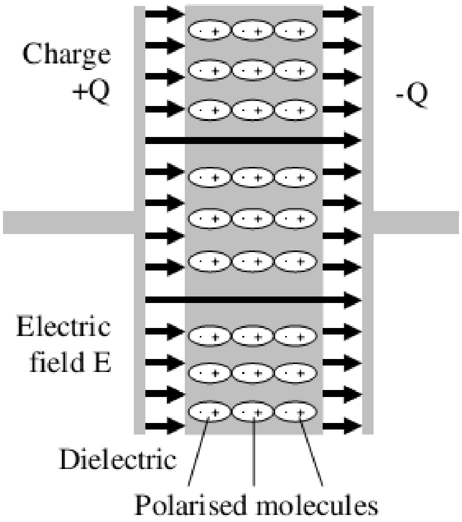


Figure-1

The electrons in the molecules shift toward the positively charged left plate. The molecules then create a leftward electric field that partially annuls the field created by the plates. (The air gap is shown for clarity; in a real capacitor, the dielectric is in direct contact with the plates.)

Perovskite Structure

Perovskite is a family name of a group of materials and the mineral name of calcium titanate ($CaTiO_3$) having a structure of the type ABO_3. Many piezoelectric (including ferroelectric) ceramics such as Barium Titanate ($BaTiO_3$), Lead Titanate ($PbTiO_3$), Lead Zirconate Titanate (PZT), Lead Lanthanum Zirconate Titanate (PLZT), Lead Magnesium Niobate (PMN), Potassium Niobate ($KNbO_3$) etc. have a cubic perovskite type structure (in the paraelectric state) with chemical formula ABO_3 (figure 2 a, b).

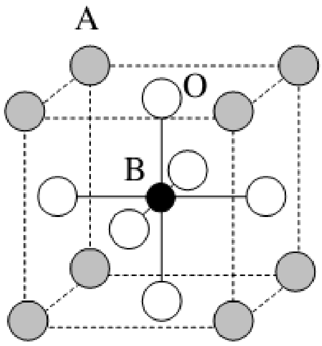


Figure 2 (a). Perovskite ABO_3 structure with the A and B cations on the corner and body center positions, respectively. Three oxygen anions per unit cell occupy the faces and form octahedra surrounding the B-site.

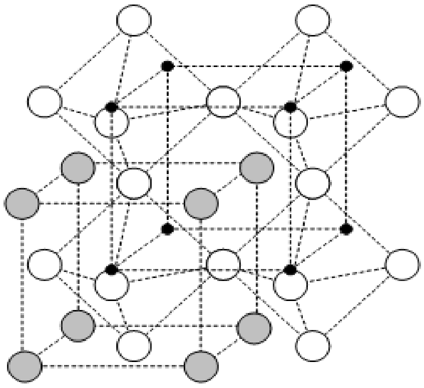


Figure 2 (b) Perovskite structure (Ba: Grey; Ti: Black; O: White)

As conventionally drawn, A-site cations occupy the corners of a cube, while B-site cations sit at the body center. Three oxygen atoms per unit cell rest on the faces. The lattice constant of these perovskite is always close to the 4 Å due to rigidity of the oxygen octahedral network and the well-defined oxygen ionic radius of 1.35 Å.

A practical advantage of the perovskites structure is that many different cations can be substituted on both the A and B sites without drastically changing the overall structure. Complete solid solutions are easily formed between many cations, often across the entire range of composition. Even though two cations are compatible in solution, their behavior can be radically different when apart from each other. Thus, it is possible to manipulate a material's properties such as Curie Temperature or dielectric constant with only a small substitution of a given cation.

All ferroelectric materials have a transition temperature called the Curie point (**T_c**). At a temperature $T > T_c$ the crystal does not exhibit ferroelectricity, while for $T < T_c$ it is ferroelectric. On decreasing the temperature through the Curie point, a ferroelectric crystal undergoes a phase transition from a non-ferroelectric (paraelectric) phase to a ferroelectric phase.

Barium Titanate ($BaTiO_3$, BT)

Barium Titanate ($BaTiO_3$) has a ferroelectric tetragonal phase (Fig-3(a)) below its curie point of about 120°C and paraelectric cubic phase (Fig-3(b)) above Curie point. The temperature of the curie point appreciably depends on the impurities present in the sample and the synthesis process.

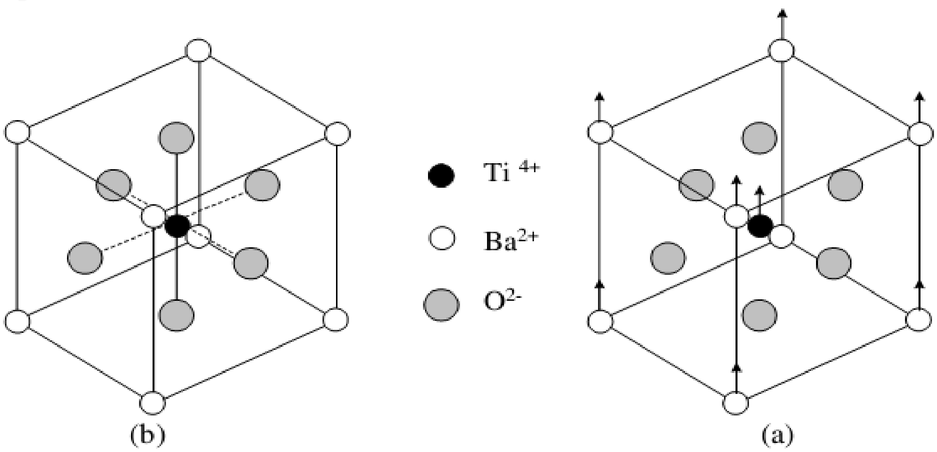


Fig 3 A Perovskite unit cell and the displacements in its ions on the application of an electric field.

In the paraelectric cubic phase the center of positive charges (Ba^{2+}, Ti^{4+}) coincid with the center of negative charges (0^{-2} ion) and on cooling below T_c, a tetragonal phase develops where the center of Ba^{2+} and Ti^{4+} ions are displaced relative to the 0^{2-} ions, leading to the formation of electric dipoles.

As the BT ceramics have a very large room temperature dielectric constant, they are mainly used in multilayer capacitor applications. The grain size control is very important for these applications.

Dielectric Constant

The dielectric constant (ε) of a dielectric material can be defined as the ratio of the capacitance using that material as the dielectric in a capacitor to the capacitance using a vacuum as the dielectric. Typical values of ε for dielectrics are:

Material	DIELECTRIC CONSTANT (ε)
Vacuum	1.000
Dry Air	1.0059
Barium Titanate	100-1250
Glass	3.8-14.5
Quartz	5
Mica	4-9
Water distilled	34-78
Soil dry	2.4-2.9
Titanium dioxide	100

Dielectric constant (ε) is given by

$$\varepsilon = \frac{C}{C_0}, \quad C_0 = \frac{\varepsilon_0 A}{t}$$

Where

C = capacitance using the material as the dielectric in the capacitor,
C_0 = capacitance using vacuum as the dielectric
ε_0 = Permittivity of free space (8.85×10^{-12} F/m)
A = Area of the plate/ sample cross section area
t = Thickness of the sample

Brief Description of the Apparatus

1. Probe Arrangement

It has two spring loaded probes. These probe move in pipes and are insulated by teflon bush, which ensure a good electrical insulation. The probe arrangement is mounted in suitable stand, which also hold the sample plate and RTD sensor. The RTD is mounted in the sample plates such that it is just below the sample, separated by a very thin sheet of mica. This ensures the correct measurement of sample temperature. This stand also serves as a lid of the oven. The leads are provided for the connection to RTD and capacitance meter.

STUDY OF DIELECTRIC CONSTANT SETUP

2. Sample

Barium Titanate ($BaTiO_3$) plate with top and bottom conducting surface.

3. Oven

This is a high quality temperature controlled oven. The oven has been designed for fast heating and cooling rates, which enhance the effectiveness of the controller.

4. Main Units

The Set-up consists of two units housed in the same cabinet.

(i) Oven Controller

Platinum RTD (A class) has been used for sensing the temperature. A Wheatstone bridge and an instrumentation amplifier are used for signal conditioning. Feedback circuit ensures offset and linearity trimming and a fast accurate control of the oven temperature.

Specifications of the Oven	
Temperature Range	: Ambient to 200 °C
Resolution	: 0.1 °C
Stability	: ± .1 °C
Measurement Accuracy	: ± 0.5 °C
Oven	: Specially designed for Dielectric measurement
Sensor	: RTD (A class)
Display	: 3½ digit, 7 segment LED with autopolarity and decimal indication
Power	: 150W

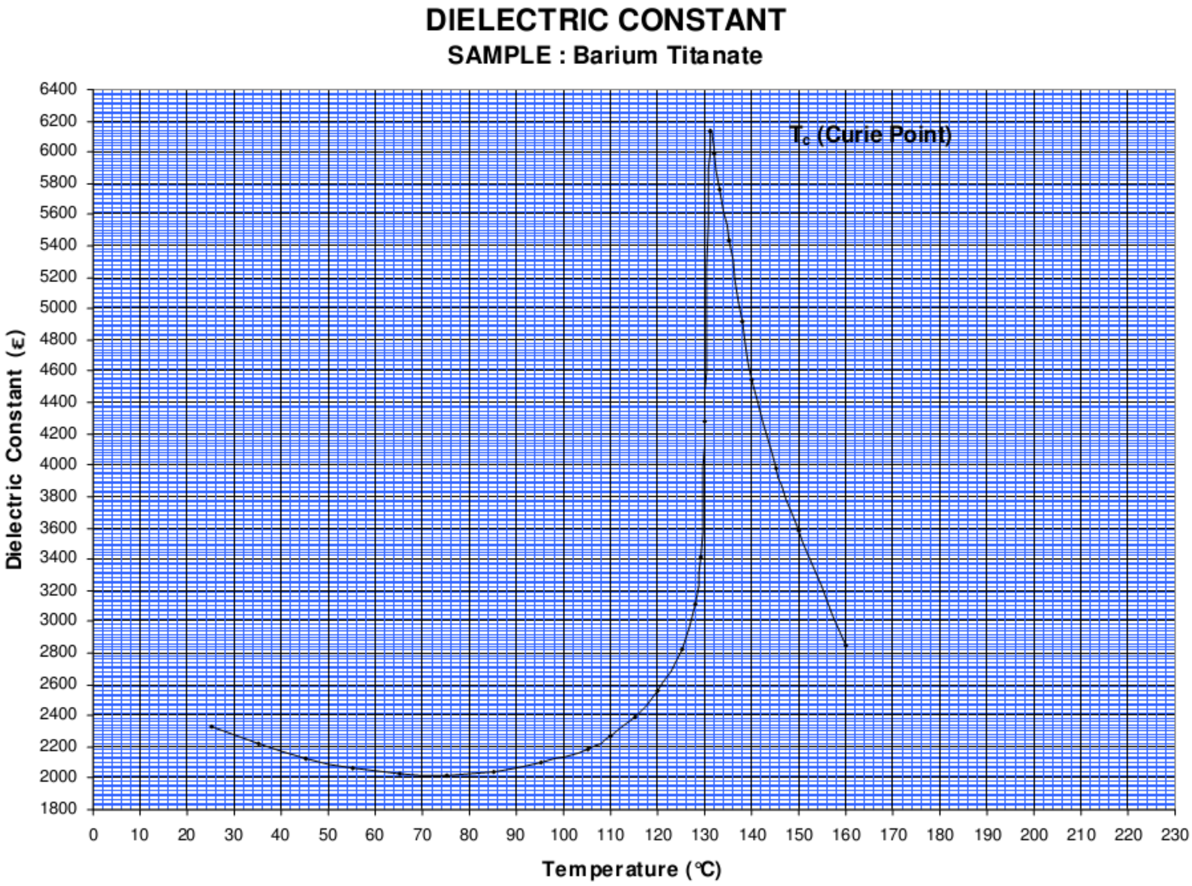
(ii) Digital Capacitance Meter

This a compact direct reading instrument for the measurement of capacitance of the sample.

Specifications of the Oven	
Range	: 50 to 6000 pf
Resolution	: 1pf
Display	: 3½ digit, 7 segment LED

Experimental Procedure

1. Put a small piece of aluminum foil on the base plate. Pull the spring loaded probes upward, insert the aluminum foil and let them rest on it. Put the sample ($BaTiO_3$) on the foil. Again pull the top of one of the probe and insert the sample below it and let it rest on it gently. Now one of the probes would be in contact with the upper surface of the sample, while the other would be in contact with the lower surface through aluminum foil.
2. Connect the probe leads to the capacitance meter.
3. Connect the oven to the main unit and put the oven in OFF position.
4. Switch on the main unit and note the value of capacitance. It should be a stable reading and is obtained directly in pf.


DIELECTRIC CONSTANT
SAMPLE : Barium Titanate
Tc (Curie Point)
Dielectric Constant (ε)
Temperature (°C)
6400
6200
6000
5800
5600
5400
5200
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230

5. (i) Switch ON the temperature Controller and approx adjust the set-temperature. The green LED would light up indicating the oven is ON and temperature would start rising. The temperature of the oven in °C would be indicated by the DPM.

(ii) The controller of the oven would switch ON/OFF power corresponding to set-temperature. In case it is less then the desired, the set-temperature may be increased or vice versa.

(iii) Because of thermal inertia of oven, there would be some over shoot and under shoot before a steady set-temperature is attained and may take 10 minutes for each reading.

(iv) To save time, it is recommended to under adjust the temperature. Example, it is desired to set at 50°C, adjust the temperature set knob so that LED is OFF at 45°C. The temperature would continue to rise. When it reaches 50°C adjust the temperature set knob so that oven is just ON/OFF. It may go up 1 & 2°C, but would settle down to 50°C. Since the change in temperature at this stage is very slow and response of RTD and sample is fast, the reading can also be taken corresponding to any temperature without waiting for a steady state.

Observations and Calculations

Sample : Barium Titanate ($BaTiO_3$)

Area (A) : 8 x 6 mm

Thickness (t) : 1.42 mm

Permittivity of Space (ε_0) : 8.85×10^{-12} F/m or 8.85×10^{-3} pf/ mm

$$\varepsilon = \frac{C}{C_0} \; ; \quad \text{where,} \quad C_0 = \frac{\varepsilon_0 A}{t} \Rightarrow \frac{8.85\times10^{-3}\times48}{1.42} \Rightarrow 29.9\times10^{-3} \text{ pf}$$

S.No.	Temperature (°C)	Capacitance, C (pf)	Dielectric Constant, (ε)
1	25	696	2328
2	35	665	2224
3	45	636	2127
4	55	618	2067
5	65	607	2030
6	75	604	2020
7	85	612	2047
8	95	629	2104
9	105	654	2187
10	110	677	2264
11	115	715	2391
12	120	764	2555
13	125	846	2829
14	128	930	3110
15	129	1020	3411
16	130	1280	4281
17	131	1836	6140
18	132	1790	5987
19	133	1722	5759
20	135	1627	5441
21	138	1470	4916

22	140	1360	4548
23	145	1190	3980
24	150	1070	3579
25	160	853	2853

Typical Results

From the graph, **Curie Temperature** (T_c) = 131°C

Precautions

(1) The spring loaded probe should be allowed to rest on the sample very gently, other wise it may damage the conducting surface of the sample or even break the sample.

(2) The reading of capacitance meter should be taken when the oven is OFF. This would be indicated by the green LED. In ON position there may be some pick ups.

(3) The reading near the Curie Temperature should be taken at closer intervals, say 1°C.

Reference

(1) Introduction to Solid State Physics – C. Kittel, Wiley Eastern Limited (5^{th} Edition).

3. Magnetic Susceptibility using a Gouy Balance

AIM:

To determine the magnetic susceptibility of a paramagnetic sample by measuring the force exerted on the sample by a magnetic field gradient

Introduction:

The electron has an intrinsic angular momentum characterized by a quantum number ½. The quantized angular momentum of a free electron is $S = \hbar\sqrt{\frac{1}{2}\left(\frac{1}{2}+1\right)}$. The intrinsic angular momentum can be crudely visualized as an intrinsic current loop which produced a magnetic moment. Thus each electron in the universe is a tiny magnet. (You will learn more about this in your quantum mechanics and atomic physics courses. Do not visualize the electron like a spinning top. Spin angular momentum is a truly intrinsic fundamental; property of the electron).

You maybe familiar with the filling of atomic shells for a many-electron atom (Hunds rule, Aufbau principle etc). Configurations in which the shell is fully filled results in zero net spin quantum number and net orbital angular momentum quantum number. Such atoms, eg. Argon, Neon etc., do not have a net magnetic moment and referred to as **diagmagents**. Atoms which do not have fully filled outer shell possess a net magnetic moment (eg. Fe, Ni etc.). A collection of such atoms which forms a gas, liquid of solid is magnetic since in the presence of an applied field the tiny moments can swing in the direction of the field. This behavior is affected by the temperature of the sample (more on this in your Statistical physics course). If the tiny moments do not 'interact' with each other the materials is referred to as a **paramagnet**. Interaction among moments results in **ferromagnets or antiferromagnets** (You will read about the origins of ferromagnetism in your statistical physics, condensed matter and atomic physics courses.[1])

Consider a paramagnet at room temperature subject to a magnetic field H. An obvious quantity of interest is the magnetization, M (magnetic moment (m_μ) per unit volume). The magnetic susceptibility (χ) is defined as ratio of the magnetization to the

[1] Just to get you interested we mention as astonishing fact: ferromagnetism arises due to a combination of the Coulomb repulsion between electrons and how it is influenced by Pauli's exclusion principle. Ferromagnetism cannot be modeled by considering dipole-dipole interactions!

applied magnetic field. The magnetization of a magnetic sample (paramagnet or ferromagnet) can be measured by a variety of methods a few of which you will be exposed to in the lab courses.

In this experiment we focus on the measurement of the force exerted on the sample by magnetic field gradient. The magnetic moment can also be measured in terms of an induced voltage in an electrical circuit (How this can be achieved ?).

Consider a solid in which each electron has an orbital angular momentum characterized by the quantum number, L, in addition to the spin angular momentum. Assuming spin-orbit coupling the total angular momentum quantum number is characterized by J. The total magnetic moment of the atom is given by $m_\mu = g\mu_B J$, where *g* is the Landè *g* factor of the atom and μ_o is the Bohr magneton ($\mu_B = e\hbar/2m$).

The difference in magnetic potential energy per unit volume between a substance of permeability μ and the displaced medium, usually air of permittivity μ_o is[2]

$$U = \left(\frac{H\cdot B}{2}\right)_{air} - \left(\frac{H\cdot B}{2\mu_o}\right)_{\text{sample}} = \frac{\mu_o H^2}{2} - \frac{\mu_o(1+\chi_m)H^2}{2} = -\mu_o\frac{H^2}{2}\chi_m \quad (1)$$

Here χ_m is the magnetic susceptibility. Which **for small magnetic fields**[3] is defined as $\chi_m = \frac{M}{H}$, where M is the magnetization.

When a magnetic field, *B*, is applied the energy changes by an amount

$$E = -m_\mu \cdot B = -VM\cdot B \quad (2)$$

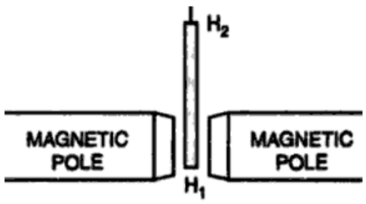
where V is the volume of the sample. Connect equations (1) and (2).

If there is a gradient in the magnetic field along the *z* direction, the sample experiences a force per unit volume given by (assuming χ_m is uniform throughout the sample)

$$f = -\frac{dU}{dz} = \frac{\mu_o\chi_m}{2}\frac{d}{dz}\left(H^2\right) \quad (3)$$

[2] Consult a book on electromagnetic theory to understand the origin of this expression.
[3] You will learn the more general expression in the statistical physics course.

Thus the force is produced by the non-uniform field. A simple way to produce a field gradient is to use a specimen in the form of a long rod or tube filled with power or liquid placed between the pole pieces of an electromagnet which produced a uniform magnetic field as shown in the figure.



Since the length over which the uniform magnetic field is produced is much smaller than the sample length, the sample experiences a field gradient. In this case the total force is given by

$$F = \int_{l_2}^{l_1} fA dz = A\frac{\mu_o \chi_m}{2}\left(H_1^2 - H_2^2\right) \approx A\frac{\mu_o \chi_m}{2}H_1^2 \qquad (4)$$

where l_1-l_2 is the length of the sample tube and A its area of cross-section and H_1 and H_2 are the magnetic field strengths along the z axis as indicated in the above figure. Now think of a physical balance in which the sample tube is hung from one side and is subject to a magnetic field. The other side has the standard weight pan as shown in figure 1. When the magnetic field is zero the weight of the sample is determined by the physical balance and is entirely due to gravity. When the field is switched on the magnetic force manifests as an apparent weight change of the sample (will the weight increase or decrease? How is this related to magnetic nature of the sample?). The force can easily be measured in terms of a weight by determining the new weight of the sample. This is known as a Guoy balance after the French physicist Louis Georges Gouy. <u>A modern version of the Guoy balance available in the laboratory uses a digital balance instead of a physical balance.</u>

Are you justified in neglecting H_2? If you keep decreasing the amount of power you take at what height does the method fail ? Verify this.

<u>APPARATUS:</u>

The Guoy balance, the powder specimen ($FeCl_2$ or Fe_2SO_4) in a glass tube, dc power supply for the magnet.

<u>PROCEDURE</u>:

The electromagnet is energized by a DC power supply. The variable magnetic field is provided by the wedge-shaped pole-pieces. The entire electromagnet is housed inside a wooden casing. The distance between the pole-pieces can be varied by means of a handle on top of the wooden casing. A digital balance is placed which carries a hook at the bottom for suspending the glass tube containing the material ($FeCl_2$, or Fe_2SO_4). The magnetic field between the pole pieces can be varied by changing the current through the coils using a DC power supply. The magnetic field corresponding to the current through the coils can be determined using a Gaussmeter (How does this work?).

1. Zero-adjust the digital balance.
2. Determine the area of cross-section of the tube. Suspend the empty glass tube as shown in Fig.1 and find its weight in zero magnetic field.
3. Using the D.C. power supply, vary the current from 0 to 3.5 A in steps of 0.2 A and in each case find the weight of the empty glass tube (Why do this?)
4. Fill the tube with the given sample (say $FeCl_2$) to about 3/4ths of the tube. Find the weight of the filled glass tube to an accuracy of 10 mg., in zero magnetic field.
5. As before, find the weight of the filled glass tube in different applied magnetic fields (both for the increasing and decreasing fields). (Why do this? When can you expect a difference in readings taken for increasing and decreasing fields)
6. Repeat the experiment with one or two more substances.

When the magnetic force is measured in terms of weight equation (3) becomes

$$mg = A\frac{\mu_o \chi_m}{2}\left(H_1^2 - H_2^2\right) \approx A\frac{\mu_o \chi_m}{2} H_1^2 \left(?\ \text{can you make this appoxmation}\right) \tag{5}$$

Plot a graph between *m* and H^2 to determine the susceptibility. This gives the susceptibility of a given volume. Compute the molar susceptibility of the sample. What is smallest susceptibility change that can be measured in the instrument? Is this sufficient to detect diamagnetism? Can you use this method for ferromagnets?

Are there gradients in the other two perpendicular directions? When can we neglect their effect?

IMPORTANT INSTRUCTIONS:

1. Reduce the current through the coils to zero slowly and then switch off the power supply.
2. DO NOT change the distance between the pole-pieces.
3. Switch off the digital balance. The glass tube is taken out of the balance and kept on the table. The power supply to the electro magnet is also turned off.

Tables

Table I

S.No.	Wt.of the empty glass tube (gm)	Current through the coils (A)	Magnetic field (Gauss)

Table II

S.No.	Wt. of the substance (gm)	Current through the coils (A)	Magnetic field (Gauss)

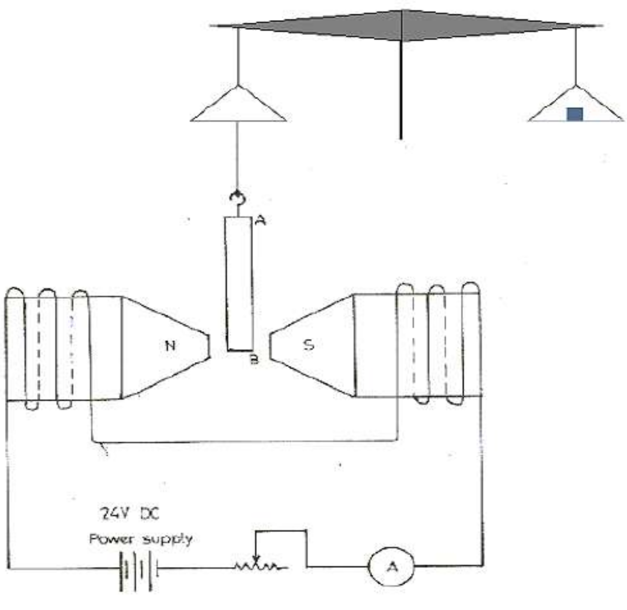


Fig. 1. The conventional Guoy balance. NS is an electromagnet with power supply and AB is the experimental glass tube. **In your experiment the physical balance will be replaced by an accurate digital balance.**

FURTHER READING:

1. Think of a way in which the susceptibility could be measured by holding the sample fixed and working with moving magnets (Known as Evan's design).
2. Think of other areas when magnetic forces play a role.

4. Study of magneto-resistance

SYMBOLS

Table 1 lists safety and electrical symbols that appear on the Instrument or in this manual.

Table 1. Safety and Electrical Symbols

Symbols	Description	Symbols	Description
	Risk of danger. Important information. See Manual.		Earth ground
	Hazardous voltage. Voltage >30Vdc or ac peak might be present.		Potentially hazardous voltage
	Static awareness. Static discharge can damage parts.		Do not dispose of this product as unsorted municipal waste. Contact SES or a qualified recycle for disposal.

Table 2. Safety Information

- Use the Instrument only as specified in this manual, or the protection provided by the Instrument might be impaired.
- Do not use the Instrument in wet environments
- Inspect the Instrument before using it. Do not use the Instrument if it appears damaged.
- Inspect the connecting lead before use. Do not use them if insulation is damaged or metal is exposed. Check the connecting leads for continuity. Replace damaged connecting leads before using the Instrument.
- Whenever it is likely that safety protection has been impaired, make the
- Instrument inoperative and secure it against any unintended operation.
- Never remove the cover or open the case of the Instrument before without first removing it from the main power source.
- Never operate the Instrument with the cover removed or the case open.
- Use only the replacement fuses specified by the manual.
- Do not operate the Instrument around explosive gas, vapor or dust.
- The equipment can remain Switched on continuously for five hours
- The equipment must remain Switched off for at least fifteen minutes before being switched on again.
- The equipment is only for the intended use

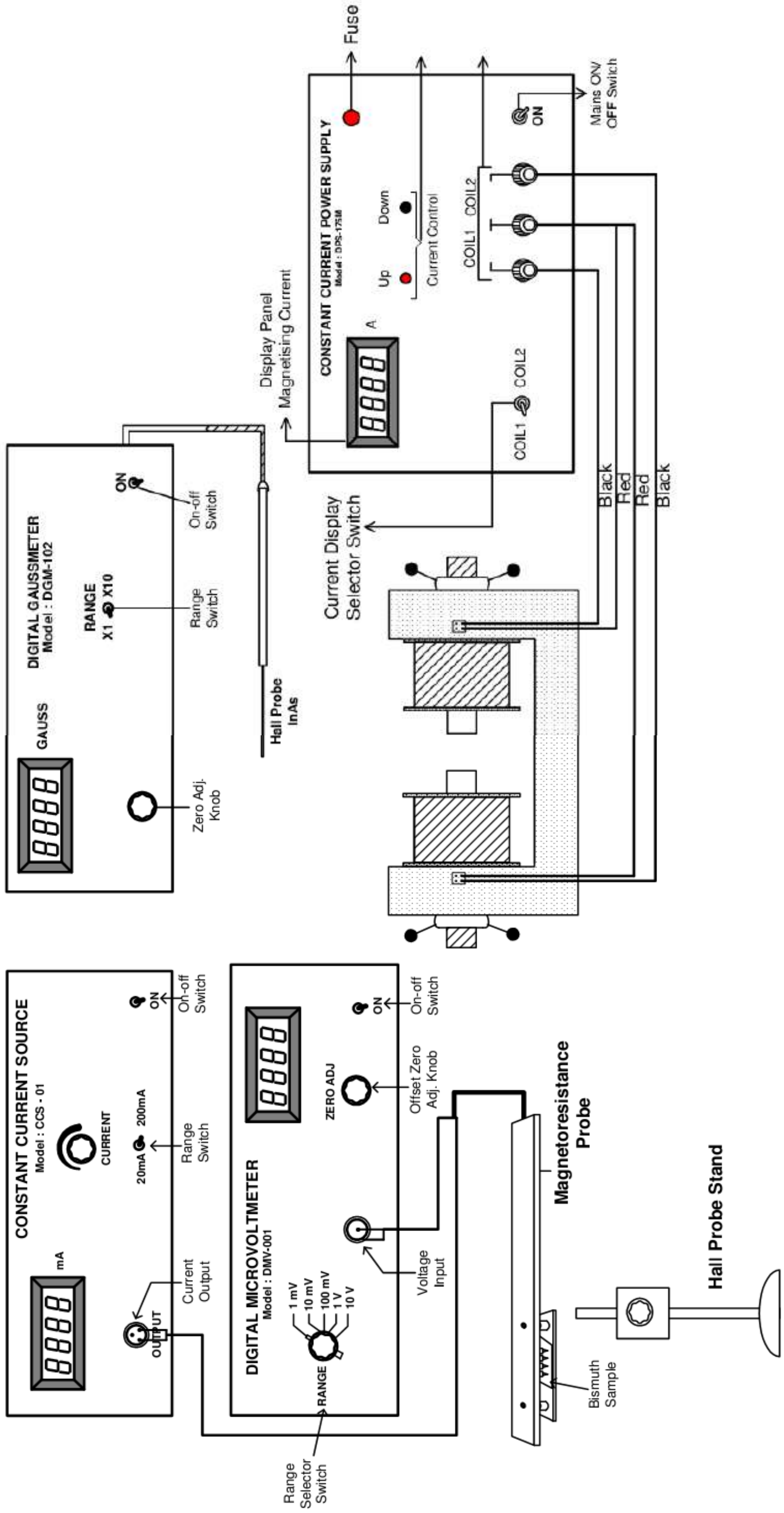


Fig.1: Panel Diagram of the magneto-resistance set up

OBJECTIVES:

(I) To determine magneto-resistance of n-Ge

(II) To study magneto-resistance of Bi

INTRODUCTION

It is noticed that the resistance of a sample changes when the magnetic field is turned on. The **Magneto-resistance** is the property of a material to change the value of its electrical resistance when an external magnetic field is applied to it. The effect was first discovered by William Thomson (more commonly known as Lord Kelvin) in 1856. The magnitude of the effect is quite low only about 1% at room temperature, but goes to about 50% at low temperatures in giant magneto resistive multilayer structures. More recently effects of more than 95% change in resistivity have been discovered in some perovskite systems.

Magneto-resistance, is due to the fact that the drift velocity of all the carriers is not same. With the magnetic field on; the Hall voltage $V = E_y t = |v \times H|$ compensates exactly the Lorentz force for carriers with average velocity; slower carriers will be over compensated and faster ones undercompensated, resulting in trajectories that are not along the applied field. This results in an effective decrease of the mean free path and hence an increase in resistivity. Here the above referred symbols are defined as: **v** = drift velocity; E = applied electric field; t = thickness of the crystal; H = Magnetic field

The change in resistivity, $\Delta\rho$, is positive for both magnetic field parallel ($\Delta\rho_{II}$) and transverse ($\Delta\rho_T$) to the current direction with $\rho_T > \rho_{II}$. There are three distinct cases of ordinary magnetoresistance, depending on the structure of the electron orbitals at the Fermi surface:

1. In metals with closed Fermi surfaces, the electrons are constrained to their orbit in k-space and the effect of the magnetic field is to increase the cyclotron frequency of the electron in its closed orbit.
2. For metals with equal numbers of electrons and holes, the magnetoresistance increases with H up to the highest fields measured and is independent of crystallographic orientation. Bismuth falls in this class.
3. Metals that contain Fermi surfaces with open orbits in some crystallographic directions will exhibit large magnetoresistance for fields applied in those directions, whereas the resistance will saturate in other directions, where the orbits are closed.

APPARATUS

1. Four probe arrangement
2. Samples: n-Ge, Bismuth
3. Constant Current Source, CCS-01
4. Digital Microvoltmeter, DMV-001
5. Electromagnet, Model EMU-75
6. Constant Current Power Supply, DPS-175
7. Digital Gaussmeter, DGM-102
8. Hall Probe Stand

BRIEF DESCRIPTION OF THE APPARATUS

(1) Four Probe arrangement

It consists of 4 collinear, equally spaced (2mm) and individually spring loaded gold plated rounded probes mounted on a PCB strip. Two outer probes are for supplying the constant current to the sample and two inner probes for measuring the voltage developed across these probes. This eliminates the error due to contact resistance which is particularly serious in semiconductors. A platform is also provided for placing the sample and mounting the four probes on it.

(2) Sample

Bismuth dimensions : 10 x 10 x 1.2mm.

(3) Constant Current Source, Model : CCS-01

It is an IC regulated current generator to provide a constant current to the outer probes irrespective of the changing resistance of the sample due to change in temperatures. The basic scheme is to use the feedback principle to limit the load current of the supply to preset maximum value. Variations in the current are achieved by a potentiometer included for that purpose. The supply is a highly regulated and practically ripples free d.c. source. The constant current source is suitable for the resistivity measurement of thin films of metals/ alloys and semiconductors like germanium**.**

SPECIFICATIONS

Range	: 0 - 200.0 mV
Resolution	: 100 μV
Accuracy	: ±0.1% of reading ±1 digit
Impedance	: 1 ohm
Special Features	: Auto Zero & polarity indicator
Special Features	: Auto Zero & polarity indicator
Overload Indicator	: Sign of 1 on the left & blanking of other digits.

Controls

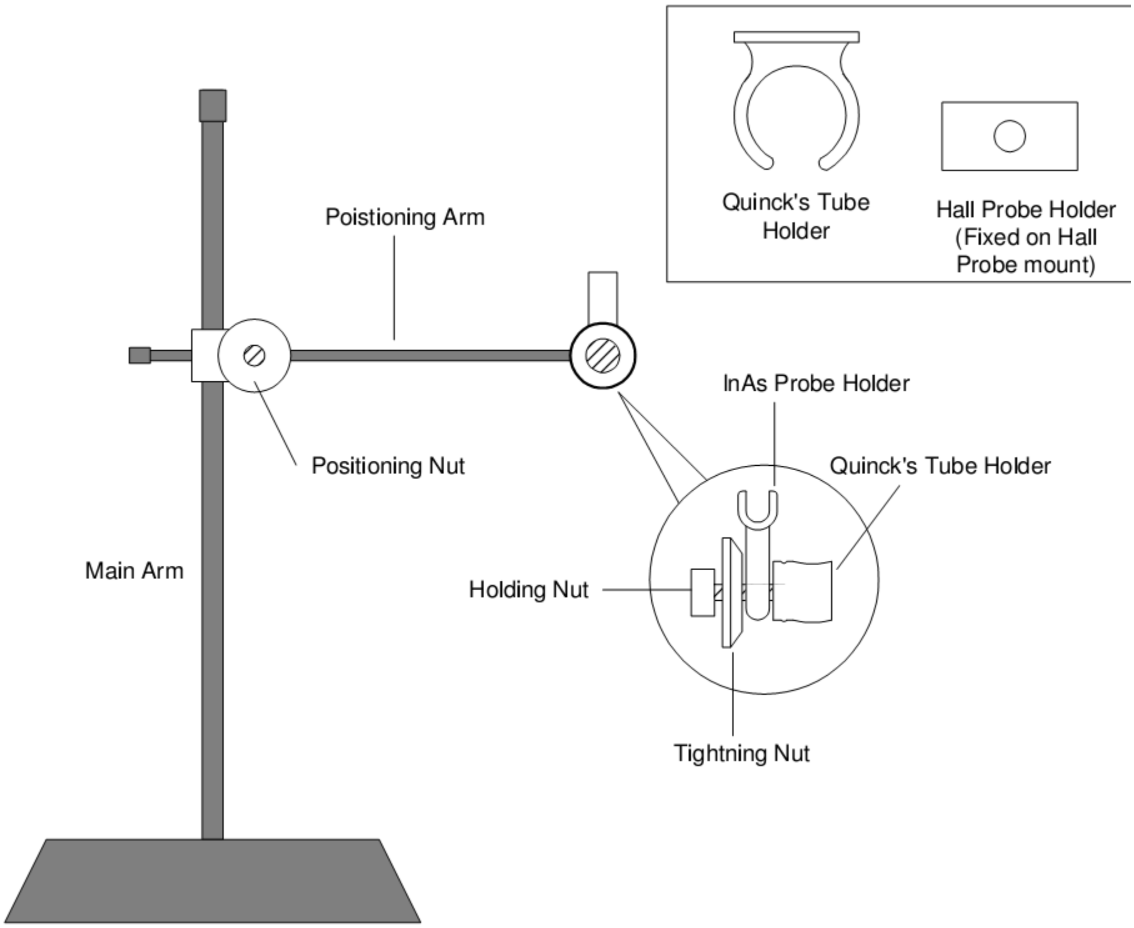
(1) Range Switch – The current meter can be switched between 20mA and 200mA range using this switch. Keep the range switch at the desired range and set the desired current using the current control knob. In case the meter shows over ranging (sign of 1 on the left and all other digits goes blank) range switch maybe shifted to higher range.

(2) Panel Meter – Display the current in mA.

(3) Current Control – This is to feed the desired current in the Sample.

(4) Current Output – Connect suitable connector from Four probe Arrangement in this connector. This will enable the unit to feed desired current in the sample

(5) ON-OFF switch – To power the unit ON/ OFF



Tips to use Multipurpose Stand

1. Set approximate position of the positioning arm and lock the same using Positioning Nut.
2. To measure the magnetic field of the electromagnet take out the Hall Probe (InAs) from the jacket/ compartment of Gaussmeter and push back the SS cover.
3. Push the SS tube part of the InAs probe in InAs holder of multipurpose stand.
4. Position the sensor tip of the Hall Probe in center of Pole Peices and lock the positioning arm using positioning nut.
5. After taking the reading replace the InAs probe in its jacket/ compartment.
6. To fix the Quinck's Tube holder, screw the Quinck's Tube holder in the holding nut kepping the tightning nut loose.
7. Once the holding nut can be turned no more, tighten the tightning nut to lock position of Quinck's Tube holder.
8. Similarly if any other Hall Probe is to be used in place of Quinck's Tube holder, tighten the Hall Probe Holder as per step 6 & 7.

Fig. 2: Multipurpose stand

1. D.C. Microvoltmeter, Model DMV-001

Digital Microvoltmeter, DMV-001 is a very versatile multipurpose instrument for the measurement of low dc voltage. It has 5 decade ranges from 1mV to 10V with 100% over-ranging. For better accuracy and convenience, readings are directly obtained on 3½ digit DPM.

This instrument uses a very well designed chopper stabilized IC amplifier. This amplifier offers exceptionally low offset voltage and input bias parameters, combined with excellent speed characteristics.

Filter circuit is provided to reduce the line pickups of 50 Hz. All internal power supplies are IC regulated.

SPECIFICATIONS

Range	:	1mV, 10mV, 100mV, 1V & 10V with 100% over ranging
Resolution	:	1μV
Accuracy	:	± 0.2%
Stability	:	Within ± 1 digit
Input Impedance	:	>1000MΩ (10MΩ on 10V range)
Display	:	3½ digit, 7 segment LED with auto polarity and decimal indication

Controls

(1) **Range Switch –** The voltmeter can be switched between 1mV, 10mV, 100mV, 1V & 10V range using this switch. Keep the range switch at lowest range for better accuracy. In case the meter shows over ranging (sign of 1 on the left and all other digits goes blank) range switch maybe shifted to higher range.

(2) **Panel Meter –** Display the Voltage in mV/ V (as per setting of Range Switch)

(3) **Zero Adj. Knob –** This is to adjust Zero of Microvoltmeter before starting the experiment.

(4) **Voltage Input –** Connect suitable connector from Four probe Arrangement in this connector. This will enable the unit to measure the voltage output of the sample

(5) **ON-OFF switch –** To power the unit ON/ OFF.

5. Electromagnet, EMU-75

Field intensity	:	11,000 ± 5% gauss in an air-gap of 10 mm. Air-gap is continuously variable upto 100 mm with two way knobbed wheel screw adjusting system.
Pole pieces	:	75 mm diameter. Normally flat faced pole pieces are supplied with the magnet
Energising coils	:	Two. Each coil is wound on non-magnetic formers and has a resistance of 12 ohms approx.
Yoke material	:	Mild steel
Power requirement	:	0 - 100 V @ 3.5 A if connected in series. 0 - 50 V @ 7.0 A if connected in parallel

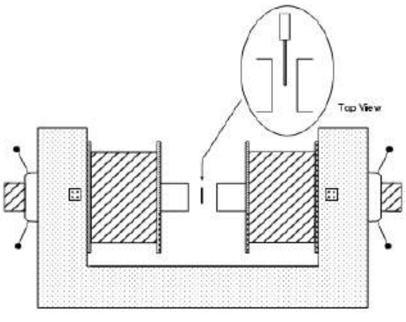


Fig. 3(a): Placing of Gaussmeter Hall probe in electromagnet

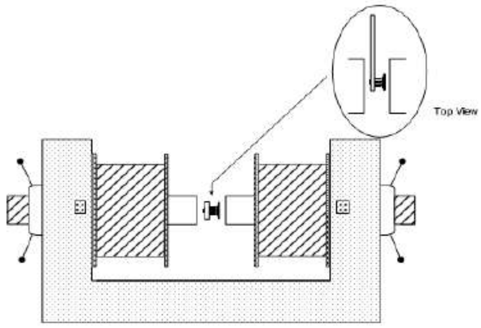


Fig. 3(b): Placing of Magneto-resistance sample probe in electromagnet

Fig. 4: Complete experimental set up

6. Constant Current Power Supply, DPS-175

The present constant current power supply was designed to be used with the electromagnet, Model EMU-75. The current requirement of 3.5 amp/coil, i.e. a total of 7 Amp was met by connecting six closely matched constant current sources in parallel. In this arrangement the first unit works as the 'master' with current adjustment control. All others are 'slave' units, generating exactly the same current as the master. All the six constant current sources are individually IC controlled and hence result in the highest quality of performance. The supply is protected against transients caused by the load inductance.

SPECIFICATIONS

Current	:	Smoothly adjustable from 0 to 3.5 A. per coil, i.e. 7A
Regulation (line)	:	$\pm$ 0.1% for 10% mains variation.
Regulation (load)	:	+ 0.1% for load resistance variation from 0 to full load
Open circuit voltage	:	50 volt
Metering	:	3½ digit, 7 segment panel meter.

7. Digital Gaussmeter, Model DGM-102

The Gaussmeter operates on the principle of Hall Effect in semiconductors. A semiconductor material carrying current develops an electro-motive force, when placed in a magnetic field, in a direction perpendicular to the direction of both electric current and magnetic field. The magnitude of this e.m.f. is proportional to the field intensity if the current is kept constant, this e.m.f. is called the Hall Voltage. This small Hall Voltage is amplified through a high stability amplifier so that a millivoltmeter connected at the output of the amplifier can be calibrated directly in magnetic field unit (gauss).

SPECIFICATIONS

Range	:	0 - 2 K gauss & 0 - 20 K gauss
Resolution	:	1 gauss at 0 - 2 K gauss range
Accuracy	:	± 0.5%
Display	:	: 3½ digit, 7 segment LED
Detector	:	Hall probe with an Imported Hall Element
Power	:	220V, 50 Hz
Special	:	Indicates the direction of the magnetic field.

7. Multipurpose Hall Probe Stand

Details Usage as given in Fig. 2.

PROCEDURE

(I) Calibration of applied magnetic field H:

1. Set the pole piece distance of the Electromagnet to nearly 19mm.
2. Now place the Hall probe of Gaussmeter in the magnetic field as shown in Fig. 3(a). Switch on the power supply for electromagnet and set it to maximum (3A). Rotate the Hall probe till it become perpendicular to magnetic field. Magnetic field reading on the Gaussmeter will be maximum in this adjustment.
3. Now lower the current from the power supply to minimum. Record the magnetic field reading on Gaussmeter by slowly varying the current.
4. Switch of the supply once you are done.
5. Plot a graph for calibration.

(II) Data for magneto resistance of n-Ge and Bi:

6. Next unscrew the screws given at the top of magneto-resistance probe to lower the base plate. Put n-Ge sample on the base plate of the four probe arrangement. Slowly screw both screws evenly to apply a very gentle pressure on the four spring probes. Check the continuity between the probes for proper electrical contacts.

   CAUTION: <u>The sample is quite brittle. Therefore, use only the minimum pressure required for proper electrical contacts.</u>

7. Place the magneto-resistance probe in the magnetic field as shown in Fig. 3b.

8. Connect the outer pair of probes to the CCS-01 terminals and the inner pair of the probes to DMV-001 terminals.
9. Switch on the mains supply of both CCS-01 and DMV-001. Adjust the current to a desired value (Say 190mA for Bi).
10. Now the DMV-001 would be reading the voltage between the probes. Adjust the range knob as required.
11. Calculate the resistance (R) of the sample in absence of magnetic field.
12. Now switch on the electromagnet power supply and set it to maximum (3A). Rotate the magneto-resistance probe till it become perpendicular to magnetic field. Voltage will be maximum in this adjustment.
13. Vary the magnetic field by varying the current of DPS-175 step by step and record the corresponding voltage reading. Determine the resistance (R_m) in presence of magnetic field and calculate ΔR (= R_m-R)
14. Plot a graph for ($\Delta R/R$) ~ H or log($\Delta R/R$)~ log H for each sample.

OBSERVATIONS

(I) Calibration of applied magnetic field at air-gap ≅ 19 mm

Table 1

S.No.	Current (A)	Magnetic Field (kG)

(II) Data for magneto resistance of n-Ge and Bi:

Probe current I = …..

S.No	Current (A)	Mag. Field H (kG)	Voltage V_m (mV)	R_m (Ω)	$\Delta R/R$	Log (H)	Log ($\Delta R/R$)

Graphs:

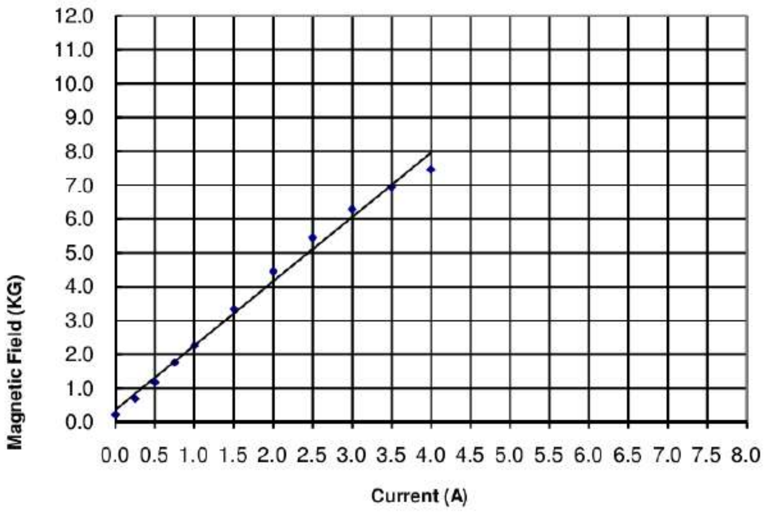


Fig. 5: Sample graph for calibration of magnetic field

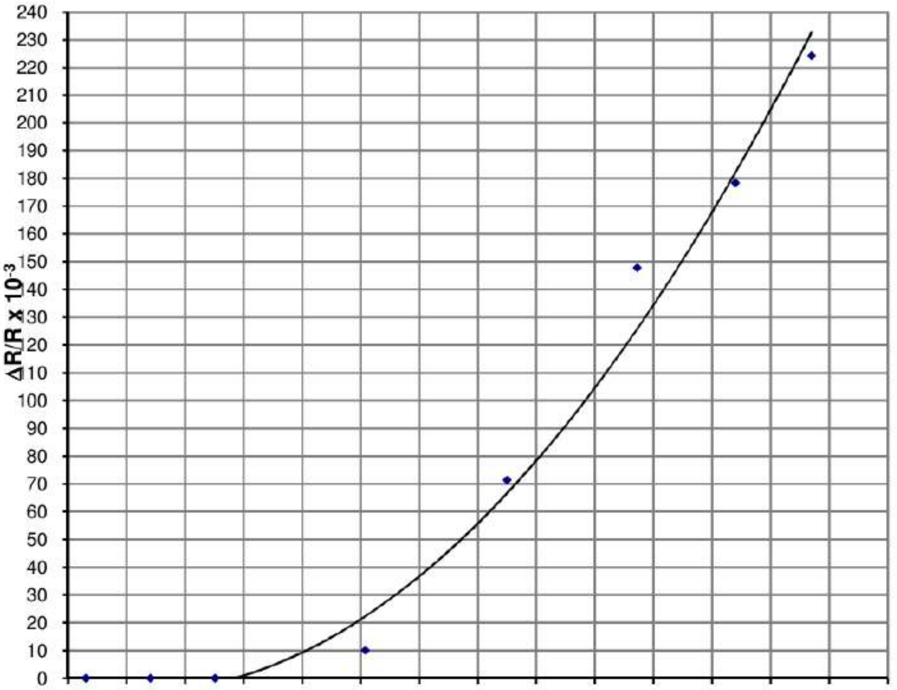


Fig. 6: Sample graph for magneto-resistance of Bi

Reference: User manual from SES

Course No: PHS 396B: Applied Electronics-I Lab

Credit: 4

1. DESIGN, CONSTRUCTION AND PERFORMANCE TESTING OF A LOGARITHMIC AMPLIFIER USING µA 741, DIODE AND MATCHED TRANSISTORS

❖ Objective

1. Performance testing of a Logarithmic amplifier using µA 741 and diode.
2. Performance testing of a Logarithmic amplifier using µA 741 and matched transistors.

❖ Theory

1. A Logarithmic amplifier using Diode

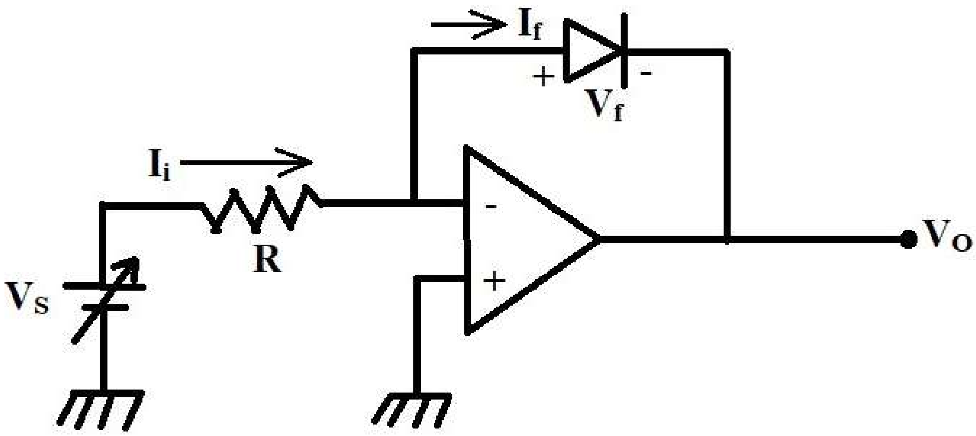


Fig. 1.1: A logarithmic amplifer using Diode

From fig.1.1 shows the circuit diagram of a logarithmic amplifier whose output is proportional to the logarithm of the input voltage. we can write

$$\frac{0 - V_S}{R} + I_f = 0 \qquad \Rightarrow I_f = \frac{V_S}{R} \qquad \dots.(1)$$

$$and \;\; 0 - V_f - V_O = 0 \qquad \Rightarrow V_f = -V_O \qquad \dots.(2)$$

V_f = The voltage drop across diode, When it is in forward bias

V_S = Input voltage   and V_o = Output voltage

When Diode in forward bias, The equation for current flowing

$$I_f = I_S e^{\left(\frac{V_f}{\eta V_T}\right)} \qquad \dots.(3)$$

I_S = The reverse saturation current of the Diode

$V_T = \frac{KT}{e}$ = Voltage equivalent of temperatre

η = 1 for Ge and approximately 2 for Si-made diode

From equ (1),(2) and (3) we get

$$\therefore I_f = I_S e^{\left(\frac{-V_O}{\eta V_T}\right)}$$

$$\Longrightarrow \frac{V_S}{RI_S} = e^{\left(\frac{-V_O}{\eta V_T}\right)}$$

$$\Rightarrow \ln\left(\frac{V_S}{RI_S}\right) = \frac{-V_o}{\eta V_T}$$

$$\Rightarrow V_o = -\eta V_T ln\left(\frac{V_S}{RI_S}\right) \qquad \text{.... (4)}$$

Thus the output voltage is proportional to the logarithm of the input voltage.

2. **A Logarithmic amplifier using matched transistors**.

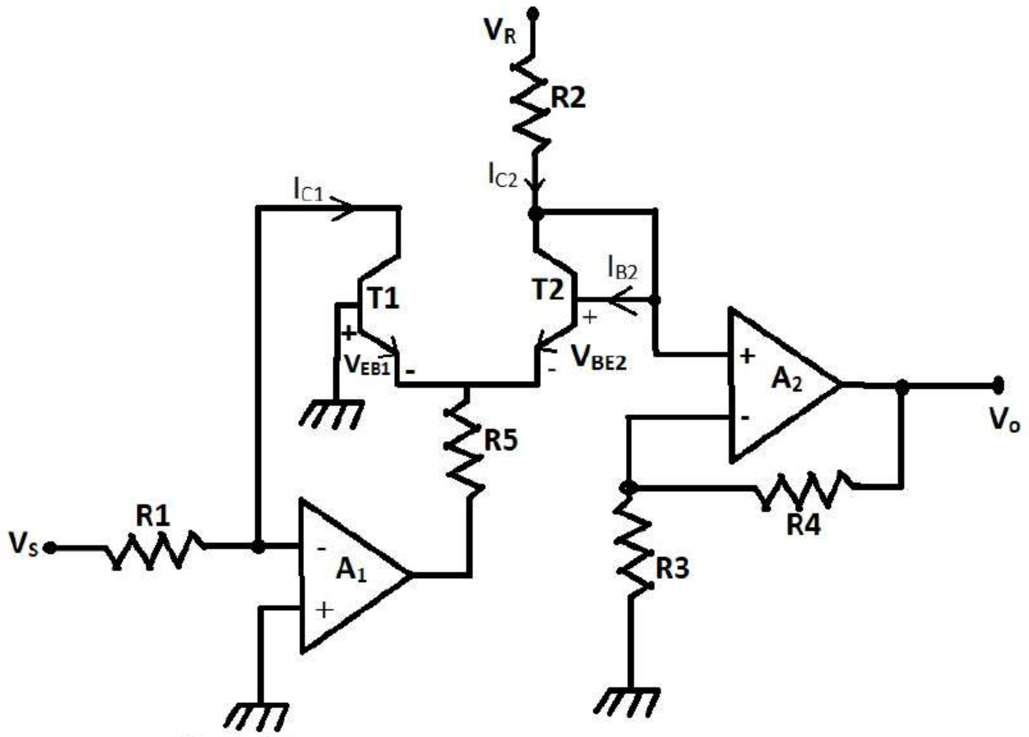


Fig. 1.2: A Logarithmic amplifier using matched transistors

It provides wide dynamic range amplification for input voltage then the diode

From Fig. 1.2, we can write

$$V^+ - V_{BE2} + V_{BE1} = 0 \qquad \Rightarrow V^+ = V_{BE2} - V_{BE1} \qquad \text{.... (5)}$$

$$For\ transistor \quad I_c = I_S \times \left(e^{\frac{V_{BE}}{V_T}} - 1\right) \qquad \text{.... (6)}$$

$$if \quad \frac{V_{BE}}{V_T} > 1 \qquad then \quad e^{\frac{V_{BE}}{V_T}} \gg 1$$

$$Thus\ we\ can\ write \ \ I_c = I_S \times \left(e^{\frac{V_{BE}}{V_T}}\right) \qquad \Rightarrow V_{BE} = V_T \times \ln\left(\frac{I_C}{I_S}\right) \qquad \text{.... (7)}$$

Assuming two transistors are matched

$$Then \quad I_{S1} = I_{S2} = I_S \qquad and \qquad V_{T1} = V_{T2} = V_T$$

$$For\ transistor\ T_1 \qquad V_{BE1} = V_{T1} \times \ln\left(\frac{I_{C1}}{I_{S1}}\right) \qquad \dots (8)$$

$$For\ transistor\ T_2 \qquad V_{BE2} = V_{T2} \times \ln\left(\frac{I_{C2}}{I_{S2}}\right) \qquad \dots (9)$$

From equation (5)

$$V^+ = V_{T2} \times \ln\left(\frac{I_{C2}}{I_{S2}}\right) - V_{T1} \times \ln\left(\frac{I_{C1}}{I_{S1}}\right)$$

$$\Rightarrow V^+ = V_T \times \ln\left(\frac{I_{C2}}{I_S}\right) - V_T \times \ln\left(\frac{I_{C1}}{I_S}\right)$$

$$\Rightarrow V^+ = V_T \times \ln\left(\frac{I_{C2}}{I_{C1}}\right) \qquad \dots (10)$$

From Fig. 1.2 $\quad I_{C1} = \frac{V_S}{R_1} \quad and \quad I_{C2} = \frac{V_R}{R_2}$

$$\therefore V^+ = -V_T \times \ln\left(\frac{V_S}{R_1} \times \frac{R_2}{V_R}\right) \qquad \dots (11)$$

$As, \quad V^+ = V_{BE2} - V_{BE1} \quad is\ very\ small \quad and \quad I_{B2} \ll I_{c2}$

$$V_O = (1 + \frac{R_4}{R_3}) \times V^+$$

$$\Rightarrow V_O = -V_T \times \left(1 + \frac{R_4}{R_3}\right) \times \ln\left(\frac{V_S}{V_R} \times \frac{R_2}{R_1}\right) \qquad \dots (12)$$

❖ Apparatus:

1. Constant Power supply(0-5)Volt
2. OP AMP µA 741
3. Diode
4. Resistor
5. Transistor
6. Voltmeter

❖ Procedure:

1. Construct the circuit of Fig. 1.1 preferably on a bread board. Choose a resistor as R. Any ordinary diode can be used. Take V_S as 0-1 volt variable dc source.
2. Adujst for offset null.
3. Vary the input V_S 0 to 1 volt in small

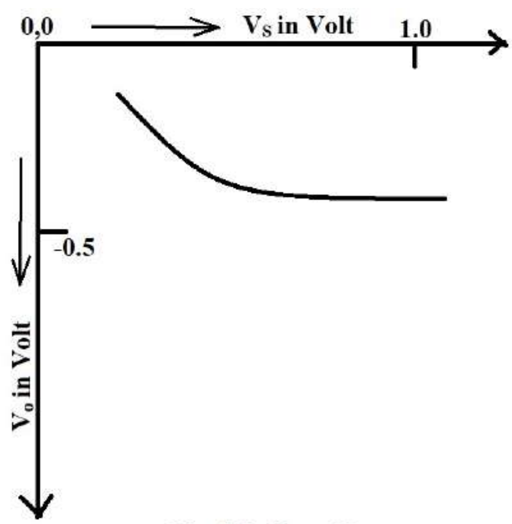


Fig. 1.3: V_S vs V_o

Steps and in each step measure the output V_O with respect to the ground.

4. Plot V_O as a function of V_S. The graph will be of the nature as shown in Fig.1.3. If V_O is plotted as a function of ln V_S, the graph will be a straight line as shown in Fig. 1.4.
5. Also for using matched transistor construct the circuit of Fig. 1.2 preferably on a bread board. And repeat the 2,3 and 4 process.

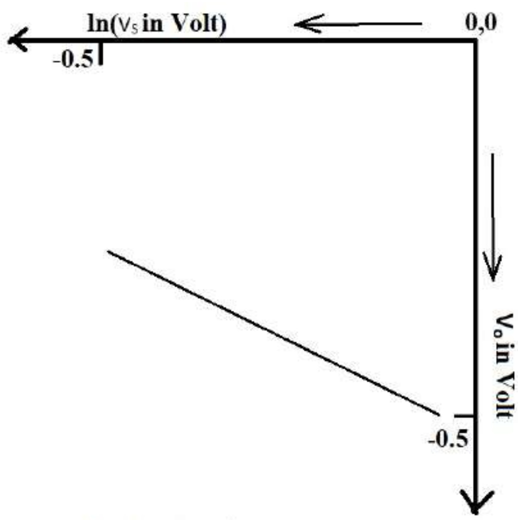


Fig. 1.4: ln(V_S) vs V_o

❖ Observations:

Specification of circuit components:

OP AMP: …

Supply voltages: …

Diode: …

Transistor: …

Resistor R, R1,R2,R3,R4,R5: …

Table 1: Data for input – output voltages for using diode:

No of obs.	1	2	3	4	…	…	etc.
Input voltage V_S in volt					…	…	etc.
ln(V_S in V)					…	…	etc.
Output voltage V_O in volt							

Table 2: Data for input – output voltages for using matched transistor:

No of obs.	1	2	3	4	…	…	etc.
Input voltage V_S in volt					…	…	etc.
ln(V_S in V)					…	…	etc.
Output voltage V_O in volt							

❖ Conclusion and discussion:

1. *The output voltage is highly dependent on temperature due to the factor V_T and the saturation current I_O.*
2. *The term $I_O R$ acts as a scale factor. Additional gain can be provided by connecting V_0 to a linear amplifier.*
3. *For proper operation of this log-amplifier V_S must be positive.*
4. *The factor η whose value normally depends on the diode current, can be eliminated by replacing the diode with a grounded base transistor. The use of transistor in place of diode maintains the exponential current-voltage relationship over a much wider voltage range.*
5. *Log-amplifier with matched transistor* provides wide dynamic range amplification for input voltage then the diode.

2. DESIGN, CONSTRUCTION AND PERFORMANCE TESTING OF AN ANTILOG AMPLIFIER USING µA 741, AND MATCHED TRANSISTORS

❖ Objective:

1. Performance testing of an Antilog amplifier using µA 741 and diode.
2. Performance testing of an Antilog amplifier using µA 741 and matched transistors.

❖ Apparatus require:

1. Constant Power supply(0-5)Volt
2. OP AMP µA 741
3. Diode
4. Resistor
5. Transistor
6. Voltmeter

❖ Theory:

1. An antilog amplifier using diode

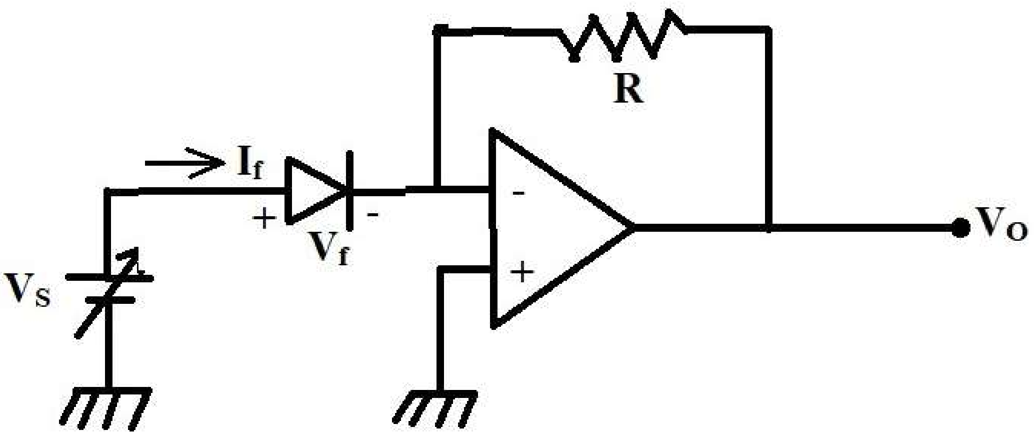


Fig. 2.1: An antilog amplifier using Diode

An amplifier whose output voltage is proportional to the antilogarithm of the input is known as antilog amplifier. Fig. 2.1 shows to build an antilog amplifier using diode.

From Fig. 2.1 we can write

$$-I_f + \frac{0 - V_O}{R} = 0 \qquad \Rightarrow I_f = -\frac{V_O}{R} \qquad \Rightarrow V_O = -R \times I_f \qquad \dots(1)$$

$$and \quad V_S - V_f = 0 \qquad \Rightarrow V_f = V_s \qquad \dots(2)$$

V_f = The voltage drop across diode, When it is in forward bias

V_S = Input voltage and V_o = Output voltage

When Diode in forward bias, the equation for current flowing

$$I_f = I_S e^{\left(\frac{V_f}{\eta V_T}\right)} \qquad \text{....(3)}$$

I_S = The reverse saturation current of the Diode

$V_T = \frac{KT}{e}$ = Voltage equivalent of temperatre

η = 1 for Ge and approximately 2 for Si-made diode

From equ (1),(2) and (3) we get

$$-\frac{V_O}{R} = I_S e^{\left(\frac{V_S}{\eta V_T}\right)}$$

$$\Rightarrow V_O = -RI_S e^{\left(\frac{V_S}{\eta V_T}\right)} \qquad \text{...(4)}$$

2. **An antilog amplifier using matched transistor**

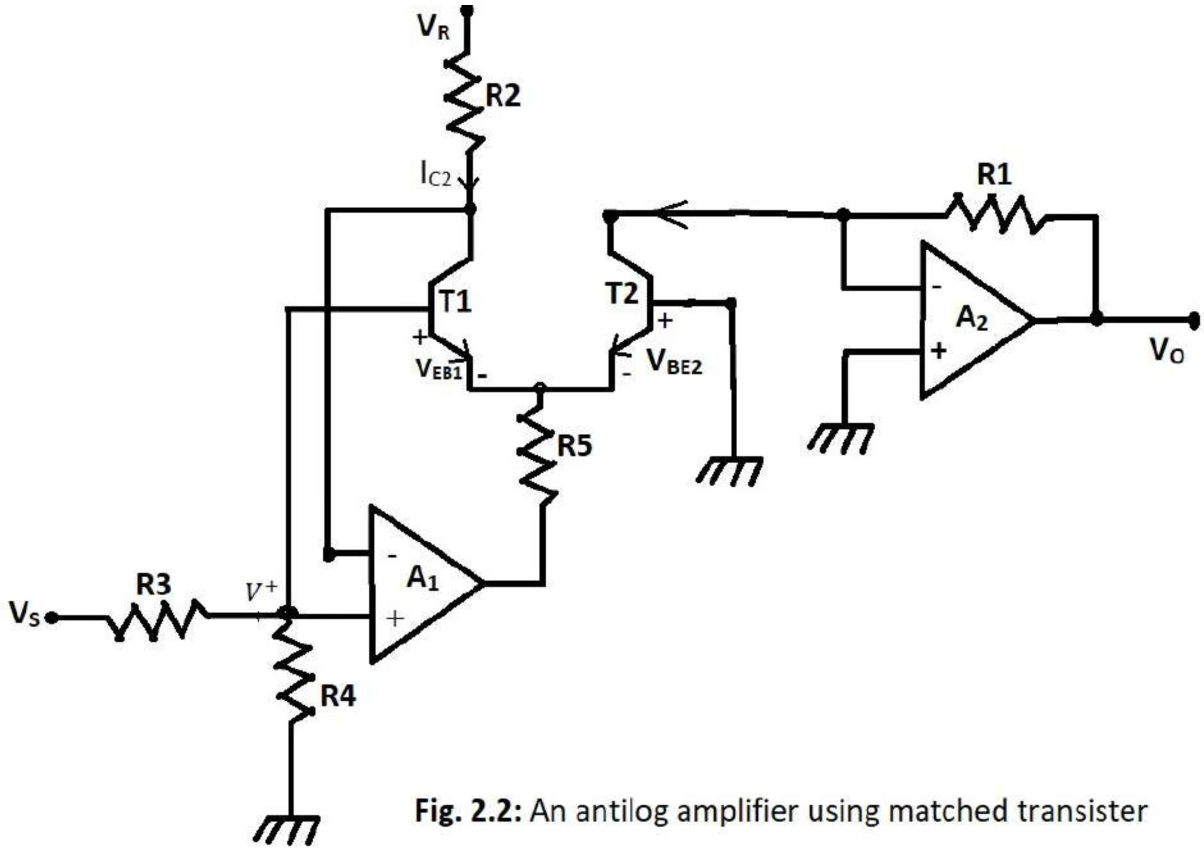


Fig. 2.2: An antilog amplifier using matched transister

The figure of anti-logarithm amplifier is shown in Fig. 2.2. Two matched transistors is used here as shown in figure, where input is given to the non-inverting amplifier pin of first op-amplifier A1

Now form Fig. 2.2 we get

$$V^+ = \frac{R_4}{R_3 + R_4} \times V_S \qquad \text{...(5)}$$

$and \;\; V^+ - V_{BE1} + V_{BE2} = 0 \qquad \Rightarrow V^+ = V_{BE1} - V_{BE2} \qquad \text{....(6)}$

$$For\ transistor \quad I_c = I_S \times \left(e^{\frac{V_{BE}}{V_T}} - 1\right) \qquad \dots (7)$$

$$if \quad \frac{V_{BE}}{V_T} > 1 \qquad then \quad e^{\frac{V_{BE}}{V_T}} \gg 1$$

$$Thus\ we\ can\ write \quad I_c = I_S \times \left(e^{\frac{V_{BE}}{V_T}}\right) \qquad \Rightarrow V_{BE} = V_T \times \ln\left(\frac{I_C}{I_S}\right) \qquad \dots (8)$$

Now, we can drive base emitter voltage of each transistor.

Base emitter voltage of 1st transistor V_{BE1} can be written as

$$V_{BE1} = V_{T1} \times \ln\left(\frac{I_{C1}}{I_{S1}}\right) \qquad \dots (9)$$

Base emitter voltage of 2nd transistor can be written as

$$V_{BE2} = V_{T2} \times \ln\left(\frac{I_{C2}}{I_{S2}}\right) \qquad \dots (10)$$

Assuming both transistors are matched. Thus, thermal voltage of 1st transistor will be same to thermal voltage of 2nd transistor and saturation current of 1st transistor will be equal to saturation current of 2nd transistor. i.e.

$$Then \quad I_{S1} = I_{S2} = I_S \qquad and \qquad V_{T1} = V_{T2} = V_T$$

Now form Fig. 2.2 we can write

$$I_{C1} = \frac{V_R - V^+}{R_2} \qquad \dots (11)$$

$$As\ we\ know\ V^+ = V_{BE1} - V_{BE2}\ is\ very\ small. Thus\ we\ can\ write\ V^+ = 0$$

$$Now\ we\ can\ write, \quad I_{C1} = \frac{V_R}{R_2} \qquad and \qquad I_{C2} = \frac{V_O}{R_1}$$

From equation (6)

$$V_{BE1} - V_{BE2} = V_{T1} \times \ln\left(\frac{I_{C1}}{I_{S1}}\right) - V_{T2} \times \ln\left(\frac{I_{C2}}{I_{S2}}\right)$$

$$\Rightarrow V_{BE1} - V_{BE2} = V_T \times \ln\left(\frac{I_{C1}}{I_S}\right) - V_T \times \ln\left(\frac{I_{C2}}{I_S}\right)$$

$$\Rightarrow V_{BE1} - V_{BE2} = V_T \times \ln\left(\frac{I_{C1}}{I_{C2}}\right) = V_T \times \ln\left(\frac{V_R}{R_2} \times \frac{R_1}{V_0}\right) = -V_T \times \ln\left(\frac{V_0}{V_R} \times \frac{R_2}{R_1}\right) \qquad \dots (12)$$

From equation (5)

$$\frac{R_4}{R_3 + R_4} \times V_S = -V_T \times \ln\left(\frac{V_0}{V_R} \times \frac{R_2}{R_1}\right)$$

$$\Rightarrow \frac{V_0}{V_R} \times \frac{R_2}{R_1} = -\frac{R_4 \times V_S}{(R_3 + R_4) \times V_T}$$

$$\Rightarrow V_0 = \frac{V_R \times R_1}{R_2} \times exp\left[-\frac{R_4 \times V_S}{(R_3 + R_4) \times V_T}\right] \qquad \dots (13)$$

This Anti-logarithmic is temperature sensitive.

❖ Procedure:

1. Construct the circuit of Fig. 2.1 preferably on a bread board. Choose a resistor as R. Any ordinary diode can be used. Take V_S as 0-1 volt variable dc source.
2. Adujst for offset null.
3. Vary the input V_S 0 to 1 volt in small teps and in each step measure the output V_O with respect to the ground.
4. Plot V_O as a function of V_S. The graph will be of the nature as shown in Fig. 2.3. If $\ln(-V_O)$ is plotted against V_S, the graph will be a straight line as shown in Fig. 2.4.
5. Also for using matched transistor construct the circuit of Fig. 2.2 preferably on a bread board. And repeat the 2,3 and 4 process.

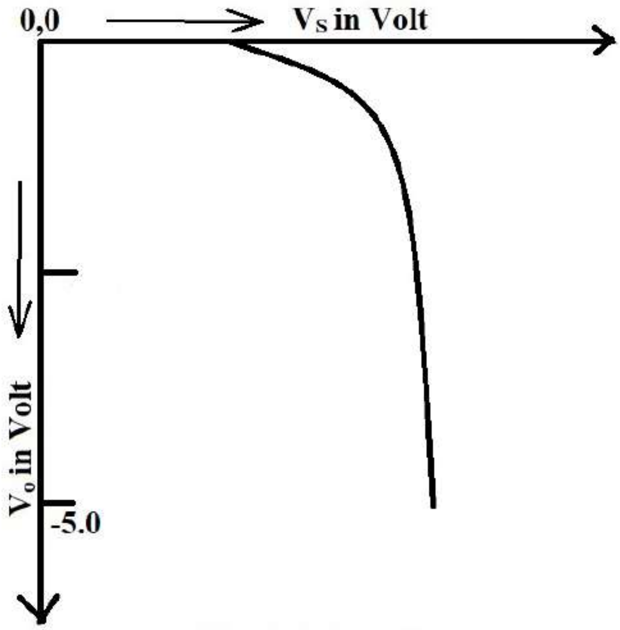


Fig. 2.3: V_S vs V_o

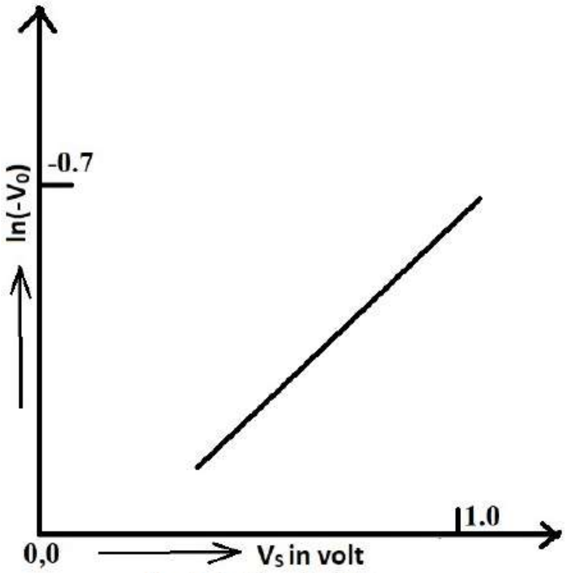


Fig. 2.4: V_S vs $\ln(-V_O)$

❖ Observations:

Specification of circuit components:

OP AMP: …

Supply voltages: …

Diode: …

Transistor: …

Resistor R, R1,R2,R3,R4,R5: …

Table 1: Data for input – output voltages for using diode:

No of obs.	1	2	3	4	…	…	etc.
Input voltage V_S in volt					…	…	etc.
Output voltage V_O in volt					…	…	etc.
$\ln(-V_0)$							

Table 2: Data for input – output voltages for using matched transistor:

No of obs.	1	2	3	4	…	…	etc.
Input voltage V_S in volt					…	…	etc.
Output voltage V_O in volt					…	…	etc.
$\ln(-V_0)$							

❖ Conclusion and discussion:

1. *The output voltage is highly dependent on temperature due to the factor V_T and the saturation current I_O.*
2. *The term I_OR acts as a scale factor. Additional gain can be provided by connecting V_0 to a linear amplifier.*
3. *For proper operation of this log-amplifier V_S must be positive.*
4. *The factor η whose value normally depends on the diode current, can be eliminated by replacing the diode with a grounded base transistor. The use of transistor in place of diode maintains the exponential current-voltage relationship over a much wider voltage range*
5. *The input volage should not be taken much greater than 0.7V. Otherwise output may saturate. Adjust the input such that the output remains well below the OP AMP supply voltages.*

3. DESIGN AND STUDY OF MULTIPLEXER: FORMATION CASCADING AND EQUATION SOLVING.

❖ **OBJECTIVE:**

(i) To demonstrate a basic Multiplexer system, and become familiar with different types of multiplexer

❖ **THEORY:**

It is not necessary to use only discrete gates (AND, OR, NAND, NOR, EXOR, EXNOR) in the design of the combinational logic circuit, with the availability of the medium scale integrated (MSI) and large scale integrated (LSI), it is possible to design a very complicated circuits with a simple procedure, for example it is waste of time in most cases to try to minimize combinational logic circuit which has eight input using tabular method, while it will simpler if we used multiplexers.

A multiplexer is a network that has many inputs and one output, and the value of the output will be the value of one of inputs which will be decided by some select lines. The simplest type of multiplexer is the two line to one line data multiplexer. Let A be one of the inputs and B is the other input and Y is the output as in Fig. 3.1, and S is the select line, then

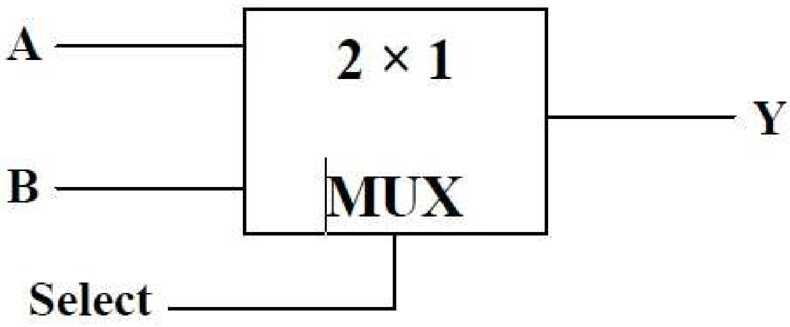


Fig. 3.1:Two to one line Multiplexer

Y = A if Select = 0.

Y = B if Select = 1.

The logic circuit diagram of the Two to One line Multiplexer is shown in Fig. 3.2.

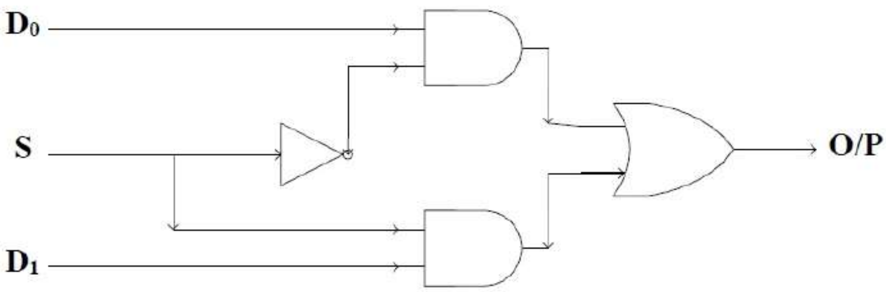


Fig. 3.2:Logic circuit of two to one line Multiplexer

There are many 2 to 1 data selectors as a MSI, for example (7498, 74157, 74158) which contains four (quadruple) two-to-one data selectors in one chip. There are other types of multiplexers 4-to-1 line, 8-to-1 line, and 16-to-1 line multiplexer, and the number of select lines of these multiplexer are 2, 3, and 4 lines respectively. Fig. 3.3 shows the four to one line multiplexer and its function block diagram.
To use the multiplexer in the design of combinational logic circuit, usually the truth table of K-map of function is used in which the table or the map is divided into 2, 4, 8, or 16 equal parts according to the type of multiplexer used. Some of the inputs of the combinational circuit is connected directly to the select lines while data lines of the multiplexer will be a function to the other inputs according to the sun map or sub tables.

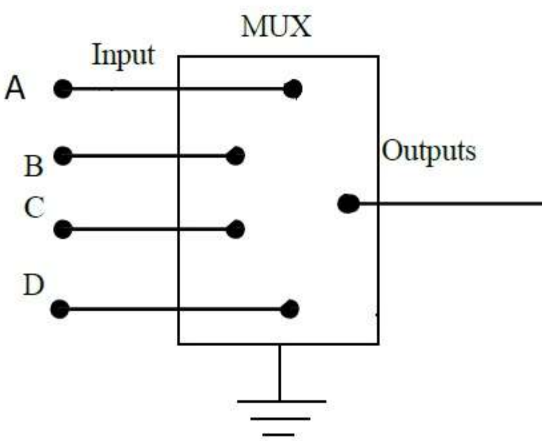


Fig. 3.3a Switch analog

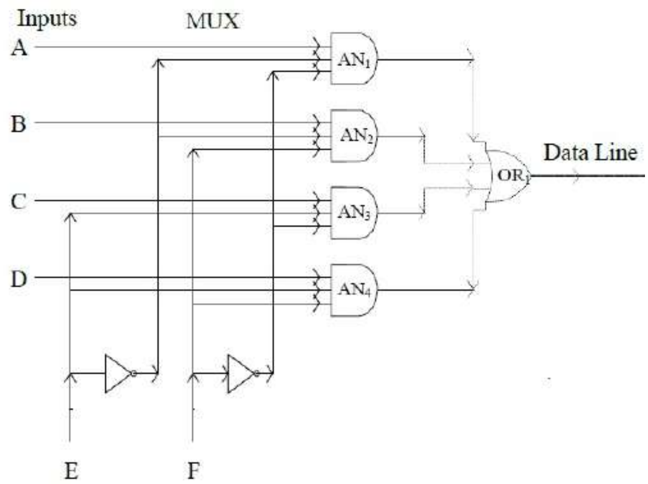


Fig. 3.3B: Logic gate circuit

Example:
Design the following expression using multiplexer.

$$\mathbf{F(A,B,C) = \bar{A}C + \bar{B}C + AB\bar{C}}$$

Solution:
Number of variables = 3, it is better to use 4-to-1 line multiplexer, i.e.:
Number of selection lines = Number of variable -1.
The truth table of the function is shown below:

A	B	C	F
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	0

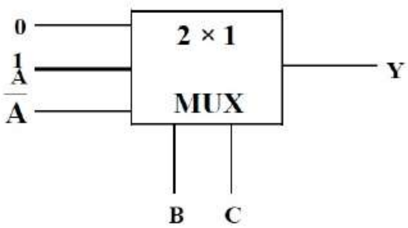
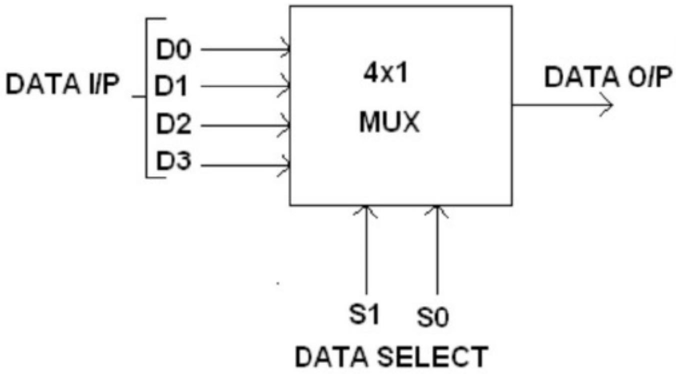


Fig. 3.4

BLOCK DIAGRAM FOR 4:1 MULTIPLEXER:

Truth Table:

S_0	S_1	Y
0	0	D_0
0	1	D_1
1	0	D_2
1	1	D_3



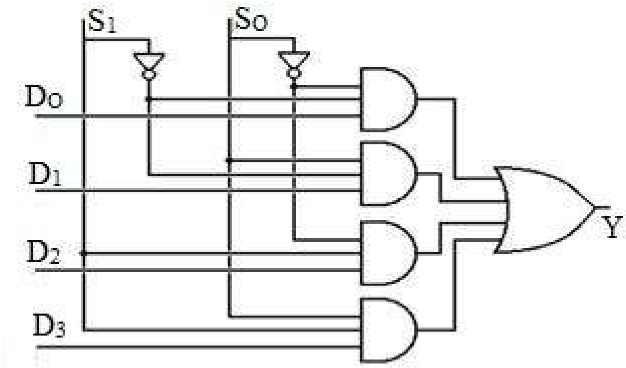


Fig. 3.5: Circuit Diagram for 4:1 Multiplexer

❖ Procedure:

1. Connections are given as per circuit diagram.
2. Logical inputs are given as per circuit diagram.
3. Observe the output and verify the truth table.

❖ Observations:

Type of IC used:

Table 1: Data for input – output voltages

Input voltage in V		Output voltage in V
S_0	S_1	Y
0.00	0.00	D_0
0.00	5.00	D_1
5.00	0.00	D_2
5.00	5.00	D_3

❖ Conclusion and discussion:

1. The bread board makes circuit connections highly flexible. There is no need of soldering or using binding screws.
2. LEDs with proper current limiting resistance can be used at the output point for easy, quick visual identification of ‘**0**’and ‘**1**’ states. If a LED glows then it is a ‘1’ state and if it doesn’t glow then it is a ‘0’ state.
3. While connecting the +5V dc supply to the ICs, special care should be taken. Connection to any wrong pin may damage the IC.

4. DESIGN AND STUDY OF DE-MULTIPLEXER: FORMATION CASCADING AND EQUATION SOLVING.

❖ **OBJECTIVE:**

(i) To demonstrate a basic Multiplexer system, and become familiar with different types of multiplexer

❖ **THEORY:**

A DE multiplexer basically reverses the multiplexing function. It is take data from one line and distribute them to given number of output lines. Fig. 4.1 shown a one to four line demultiplexer circuit. The input data line goes to all of the AND gates. The two select lines enable only one gate at a time and the data appearing on the input line will pass through the selected gate to the associated output line.

The simplest type of demultiplexer is the one to two lines DMUX. as shown in Fig. 4.2.

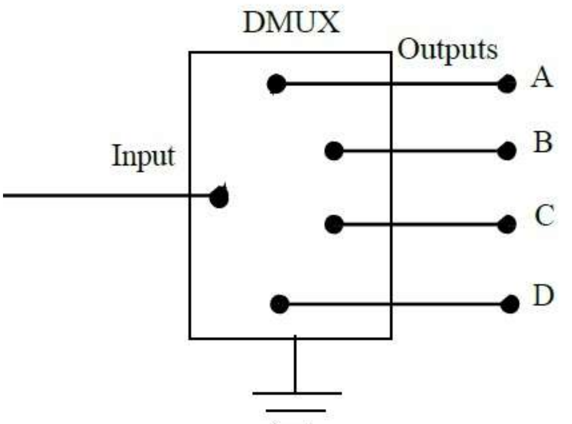


Fig. 4.1: switch analog

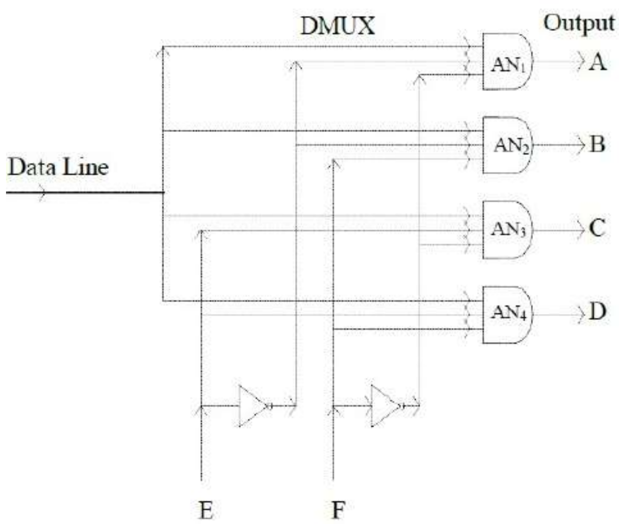


Fig. 4.2: Logic gate circuit

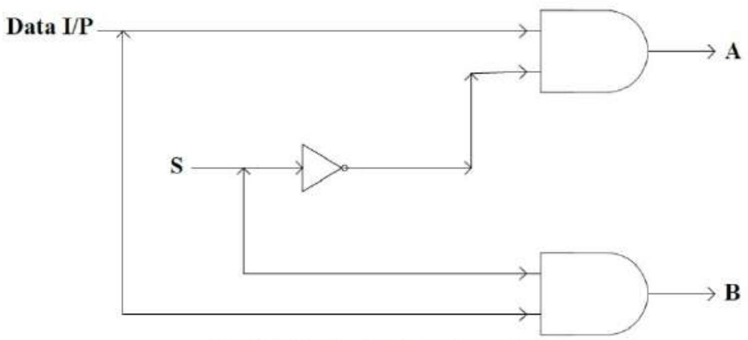


Fig. 4.3: One to two lines demultiplexer

Truth Table

S1	S0	INPUT
0	0	$X \rightarrow D0 = X\, S1'\, S0'$
0	1	$X \rightarrow D1 = X\, S1'\, S0$
1	0	$X \rightarrow D2 = X\, S1\, S0'$
1	1	$X \rightarrow D3 = X\, S1\, S0$

$Y = X\, S1'\, S0' + X\, S1'\, S0 + X\, S1\, S0' + X\, S1\, S0$

❖ Procedure:

4. Connections are given as per circuit diagram.
5. Logical inputs are given as per circuit diagram.
6. Observe the output and verify the truth table.

❖ Observations:

Type of IC used:

Table 1: Data for input – output voltages

Input voltage in V		Output voltage in V
S_0	S_1	Y
0.00	0.00	D_0
0.00	5.00	D_1
5.00	0.00	D_2
5.00	5.00	D_3

❖ Conclusion and discussion:

1. The bread board makes circuit connections highly flexible. There is no need of soldering or using binding screws.
2. LEDs with proper current limiting resistance can be used at the output point for easy, quick visual identification of ‘**0**’and ‘**1**’ states. If a LED glows then it is a ‘1’ state and if it doesn’t glow then it is a ‘0’ state.
3. While connecting the +5V dc supply to the ICs, special care should be taken. Connection to any wrong pin may damage the IC.

4. Design of an Active high pass/Low pass second order Butterworth filter.

❖ Objectives:

To construct and analyse the frequency response of

i) An active low pass second order Butterworth filter

ii) An active high pass active second order Butterworth filter

❖ Circuit Components/Equipment's:

(i) OP AMP (IC741), (ii) Resistors, (iii) Capacitors, (iv) Oscilloscope, (v) Function generator, (vi) Breadboard, (vii) Connecting wires.

❖ Overview:

The main disadvantage of passive filters is the fact that the maximum gain that can be achieved with these filters is 1. In other words, the maximum output voltage is equal to the input voltage. If we make filter the gain can be greater than 1. The circuits employed are all based on the inverting OP AMPs with the addition of a capacitor placed in the correct position for the particular type of filter. These circuits are called active filter circuit because they use OP AMPs which require a power supply.

1)Active low pass second order Butterworth filter

The practical response of Second Order Low Pass Butterworth Filter must be very close to an ideal one. In case of low pass filter, it is always desirable that the gain rolls off very fast after the cut off frequency, in the stop band. In case of first order filter, it rolls off at a rate of 20 dB/decade. In case of second order filter, the gain rolls off at a rate of 40 dB/decade. Thus, the slope of the frequency response after $f = f_H$ is — 40 dB/decade, for a second order low pass filter.

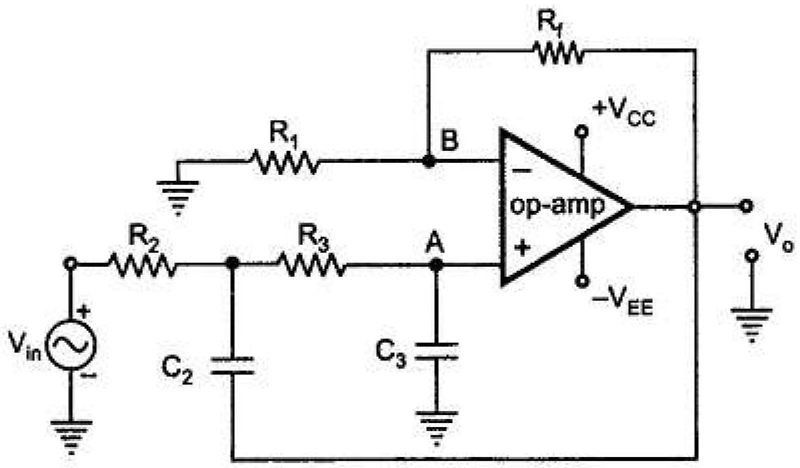


Fig. 5.1: Second order low pass butterworth filter

The standard form of Second Order Butterworth Filter Transfer Function of any second order system is

$$\frac{V_0(S)}{V_{in}(S)} = \frac{A}{S^2+2\xi\omega_n s+\omega_n^2} \qquad \ldots(1)$$

where

- A = overall gain
- ξ = damping of system
- ω_n = natural frequency of oscillations

use the Laplace transform method we can derived that

$$\frac{V_0}{V_{in}} = \frac{A_F}{S^2 + \frac{(R_3C_3 + R_2C_3 + R_2C_2 - A_F R_2C_2)S}{R_2R_3C_2C_3} + \frac{1}{R_2R_3C_2C_3}} \quad \dots (2)$$

Comparing (1) and (2), we can say that

$$\omega_n^2 = \frac{1}{R_2R_3C_2C_3}$$

In case of Second Order Low Pass Butterworth Filter, this frequency is nothing but the cut-off frequency, ω_H

$$\omega_H^2 = \frac{1}{R_2R_3C_2C_3}$$

$$\Rightarrow (2\pi f_H)^2 = \frac{1}{R_2R_3C_2C_3}$$

$$\Rightarrow f_H = \frac{1}{2\pi\sqrt{R_2R_3C_2C_3}}$$

This is the required cut off frequency.

Replacing s by j_ω, the transfer function can be written in the frequency domain and hence, finally, can be expressed in the polar form as,

$$\frac{V_0}{V_{in}} = \left|\frac{V_0}{V_{in}}\right| < \emptyset \quad \text{and} \quad \left|\frac{V_0}{V_{in}}\right| = \frac{A_F}{\sqrt{1+(\frac{f}{f_H})^4}}$$

Where

- A_F = gain in filter in pass band
- f = input frequency in Hz
- f_H = high cut-off frequency in Hz

The frequency response is shown in Fig. 5.2

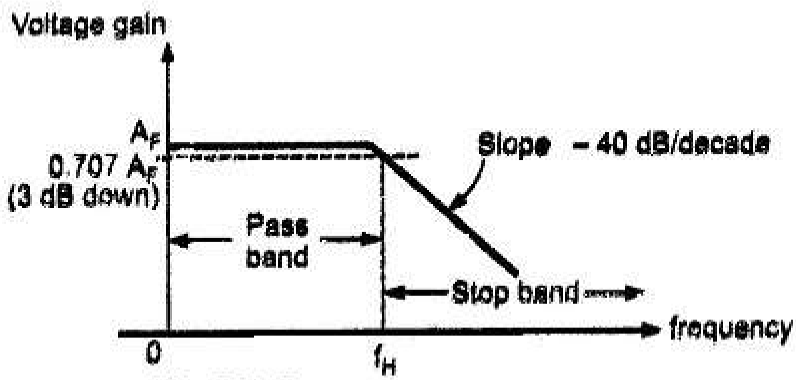


Fig. 5.2: Frequency response

At the cut off frequency f_H, the gain is 0,707 A_F i,e. 3 dB down from its 0 Hz level. After, f_H ($f > f_H$), the gain rolls off at a frequency rate of 40 dB/decade,. Hence, the slope of the response after f_H is – 40 dB/decade.

2)Active high pass active second order Butterworth filter

The second order high pass Butterworth filters produces a gain roll off at the rate of + 40 dB/decade in the stop band. This filter also can be realized by interchanging the positions of resistors and capacitors in a second order low pass Butterworth filters. The Fig. 5.3 shows the second order high pass Butterworth filters.

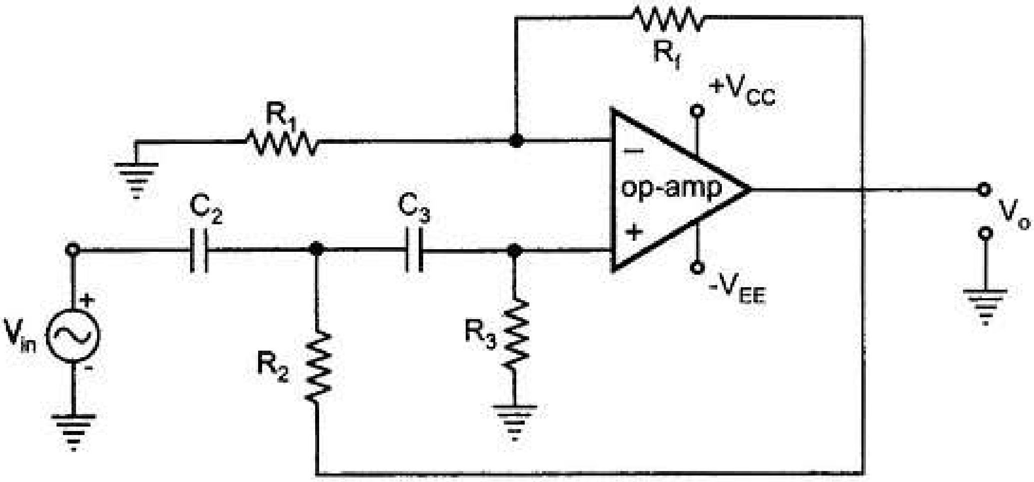


Fig. 5.3 Second order high pass Butterworth filter

The analysis for this filter is exactly same as that of second order low pass Butterworth filter. The resulting expression is given here for the convenience of the reader. The voltage gain magnitude equation for the second order high pass filter is

$$\left|\frac{V_0}{V_{in}}\right| = \frac{A_F}{\sqrt{1 + (\frac{f_L}{f})^4}}$$

where

- f = input frequency in Hz
- f_L = lower cut off frequency in Hz ≈1/2πRC
- $R_2 = R_3 = R$ and $C_2 = C_3 = C$
- A_F = passband gain
  = 1.586 to ensure second order butterworth response

and $R_f = 0.586R_1$

The frequency response of this filter is shown in the Fig. 5.4

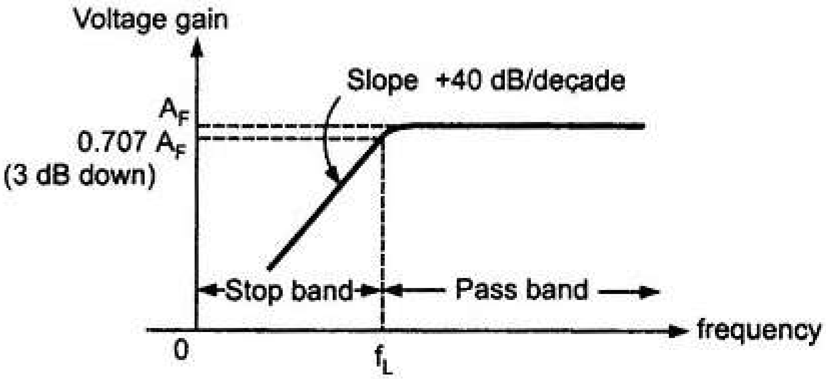


Fig. 5.4 Frequency Response

❖ Procedure:

The design steps for Second Order Low Pass Butterworth Filter are

1) Choose the cut-off frequency f_H,
2) The design can be simplified by selecting $R_2 = R_3 = R$ and $C_2 = C_3 = C$ and choose a value of C less than or equal to 1 μF.
3) Calculate the value of R from the equation,

$$f_H = \frac{1}{2\pi\sqrt{R_2 R_3 C_2 C_3}} = \frac{1}{2\pi RC}$$

As $R_2 = R_3 = R$ and $C_2 = C_3 = C$, the pass band voltage gain $A_F = (1 + R_f/R_1)$ of the second order low pass filter has to be equal to 1.586.

Note: For $R_2 = R_3 = R$ and $C_2 = C_3 = C$, the transfer function takes the form

$$\frac{V_0}{V_{in}} = \frac{A_F}{S^2 + \frac{(3-A_F)S}{RC} + \frac{1}{R^2C^2}}$$

From this we can write that,

$$\xi = \text{damping factor} = \frac{3 - A_F}{2}$$

Now, for Second Order Low Pass Butterworth Filter, the damping factor required is 0.707, from the normalized Butterworth polynomial.

$$\therefore 0.707 = \frac{3 - A_F}{2} \qquad \Rightarrow A_F = 1.586$$

Thus, to ensure the **Butterworth response**, it is necessary that the gain A_f is 1.586

$$1.586 = 1 + \frac{R_f}{R_1} \qquad \Rightarrow R_f = 0.586 R_1$$

Hence, choose a value of $R_1 \leq 100$ kΩ and calculate the corresponding value of R_f

5. Frequency Scaling:

Once the filter is designed, sometimes, it is necessary to change the value of cut-off frequency f_H. The method used to change the original cut-off frequency f_H to a new cut-off frequency f_{H1} is called as frequency scaling.

To achieve such a frequency scaling, the standard value capacitor C is selected first. The required cut-off frequency can be achieved by calculating corresponding value of resistance R. But to achieve frequency scaling a potentiometer is used as sho $\frac{V_o(pp)}{V_i(pp)}$ Fig. 2.78. Thus, the resistance R is generally a potentiometer with which required cut-(quency f_H can be adjusted and changed later on if required.

5)From your measurements determine the gain, $\frac{V_O(PP)}{V_i(PP)}$ and compare with the calculated value.

6) Plot log f ~ gain (dB)

❖ Observations:

1)Active low pass second order Butterworth filter

Table:

Sl. No.	Frequency, f (kHz)	V_{in}(pp) (Volt)	V_o(pp) (Volt)	Gain,A_V= $\frac{V_o(pp)}{V_i(pp)}$	Gain (dB)
1					
2					
..					
..					

2)Active high pass active second order Butterworth filter

Table:

Sl. No.	Frequency, f (kHz)	V_{in}(pp) (Volt)	V_o(pp) (Volt)	Gain,A_V= $\frac{V_o(pp)}{V_i(pp)}$	Gain (dB)
1					
2					
..					
..					

❖ Conclusion and discussion:

Course No: PHS 396D
Astrophysics I (PRACTICAL)
Marks: 50, Credit: 4

Sl. No	Experiment	Page No.
1	Identification of following objects with naked eyes or a binocular. a) Mercury, b) Venus, c) Mars, d) Jupiter e) Saturn, f) North Pole, f) The Big Dipper (Ursa Major) g) The Little Dipper (Ursa Minor), h) Betelgeuse and i) Cassiopeia.	66
2	Study of movement of Moon between rise to set time.	83
3	Study of movement of a planet in sky between rise to set of the planet.	85
4	Identify Sun spots with a solar-filter or a mirror.	88
5	Different Fitting techniques (linear and non-linear, fits to data with experimental errors, evaluating goodness of fit, etc.) and error analysis.	89
6	Study of Light curve of astronomical sources in different energy band.	91
7	Study of power spectrum of different astronomical sources.	92

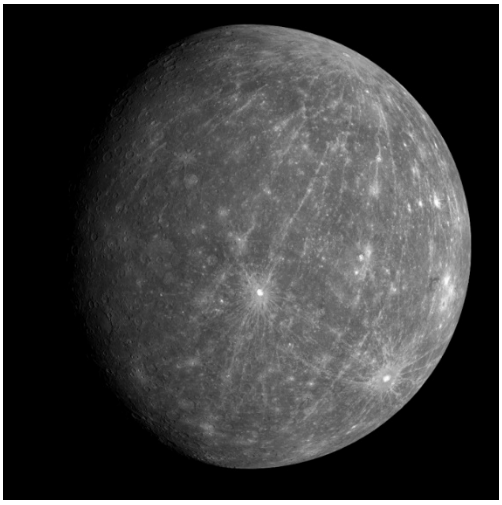
1. Identification of following objects with naked eyes or a binocular.
a) Mercury, b) Venus, c) Mars, d) Jupiter e) Saturn, f) North Pole, f) The Big Dipper (Ursa Major) g) The Little Dipper (Ursa Minor), h) Betelgeuse and i) Cassiopeia.

- **Objective: -** With time, all astronomical sources change position in the sky. Due to proximity, the movement of solar system bodies are faster than distant stars. We will try to detect them and observe them.

❖ Theory

a) Mercury

Mercury is the smallest planet in the Solar System and the closest to the Sun. Its orbit around the Sun takes 87.97 Earth days, the shortest of all the Sun's planets. It is named after the Roman god *Mercurius* (Mercury), god of commerce, messenger of the gods, and mediator between gods and mortals, corresponding to the Greek god Hermes (Ἑρμῆς). Like Venus, Mercury orbits the Sun within Earth's orbit as an inferior planet; its apparent distance from the Sun as viewed from Earth never exceeds 28°. This proximity to the Sun means the planet can only be seen near the western horizon after sunset or the eastern horizon before sunrise, usually in twilight. At this time, it may appear as a bright star-like object, but is more difficult to observe than Venus. From Earth, the planet telescopically displays the complete range of phases, similar to Venus and the Moon, which recurs over its synodic period of approximately 116 days. Due to its synodic proximity to Earth, Mercury is most often the closest planet to Earth, with Venus periodically taking this role.
Mercury rotates in a way that is unique in the Solar System. It is tidally locked with the Sun in a 3:2 spin–orbit resonance, meaning that relative to the fixed stars, it rotates on its axis exactly three times for every two revolutions it makes around the Sun. As seen from the Sun, in a frame of reference that rotates with the orbital motion, it appears to rotate only once every two Mercurian years. An observer on Mercury would therefore see only one day every two Mercurian years.



(Mercury, credit: NASA)

Observation: Due to proximity to the size and small size of the planet, it is not easy to observe Mercury with naked eyes. Mercury's apparent magnitude is calculated to vary between −2.48 (brighter than Sirius) around superior conjunction and +7.25 (below the limit of naked-eye visibility) around inferior conjunction. The mean apparent magnitude is 0.23 while the standard deviation of 1.78 is the largest of any planet. The mean apparent magnitude at superior conjunction is −1.89 while that at inferior conjunction is +5.93. Observation of Mercury is complicated by its proximity to the Sun, as it is lost in the Sun's glare for much of the time. Mercury can be observed for only a brief period during either morning or evening twilight.

But in some cases, Mercury can better be observed in daylight with a telescope when the position is known because it is higher in the sky and less atmospheric effects affect the view of the planet. When proper safety precautions are taken to prevent inadvertently pointing the telescope at the Sun (and thus blinding the user), Mercury can be viewed as close as 4° to the Sun when near superior conjunction when it is almost at its brightest.

Mercury can, like several other planets and the brightest stars, be seen during a total solar eclipse.

Like the Moon and Venus, Mercury exhibits phases as seen from Earth. It is "new" at inferior conjunction and "full" at superior conjunction. The planet is rendered invisible from Earth on both of these occasions because of its being obscured by the Sun, except its new phase during a transit.

Mercury is technically brightest as seen from Earth when it is at a full phase. Although Mercury is farthest from Earth when it is full, the greater illuminated area that is visible and the opposition brightness surge more than compensates for the distance. The opposite is true for Venus, which appears brightest when it is a crescent, because it is much closer to Earth than when gibbous.

Nonetheless, the brightest (full phase) appearance of Mercury is an essentially impossible time for practical observation, because of the extreme proximity of the Sun. Mercury is best observed at the first and last quarter, although they are phases of lesser brightness. The first and last quarter phases occur at greatest elongation east and west of the Sun, respectively. At both of these times Mercury's separation from the Sun ranges anywhere from 17.9° at perihelion to 27.8° at aphelion. At greatest *western* elongation, Mercury rises at its earliest before sunrise, and at greatest *eastern* elongation, it sets at its latest after sunset.

Mercury is more often and easily visible from the Southern Hemisphere than from the Northern. This is because Mercury's maximum western elongation occurs only during early autumn in the Southern Hemisphere, whereas its greatest eastern elongation happens only during late winter in the Southern Hemisphere. In both of these cases, the angle at which the planet's orbit intersects the horizon is maximized, allowing it to rise several hours before sunrise in the former instance and not set until several hours after sundown in the latter from southern mid-latitudes, such as Argentina and South Africa.

An alternate method for viewing Mercury involves observing the planet during daylight hours when conditions are clear, ideally when it is at its greatest elongation. This allows the planet to be found easily, even when using telescopes with 8 cm (3.1 in) apertures. However, great care must be taken to obstruct the Sun from sight because of the extreme risk for eye damage. This method bypasses the limitation of twilight observing when the ecliptic is located at a low elevation (e.g. on autumn evenings).

Tabulation:

Date and time:

The location of observation:

Longitude:

Latitude:

Sky condition:

Moon phase:

Time	Location of the object	Observational details

Discussion:

1. Discuss about what you see about the object.
2. Discuss weather condition and whether it affects the observation of the object.
3. What could be done to improve the observation (if possible).
4. Miscellaneous.

b) Venus

Venus is the second planet from the Sun. It is sometimes called Earth's "sister" or "twin" planet as it is almost as large and has a similar composition. As an interior planet to Earth, Venus (like Mercury) appears in Earth's sky never far from the Sun, either as morning star or evening star. Aside from the Sun and Moon, Venus is the brightest natural object in Earth's sky, capable of casting visible shadows on Earth at dark conditions and being visible to the naked eye in broad daylight.

Venus is the second largest terrestrial object of the Solar System. It has a surface gravity slightly lower than on Earth and has a weak induced magnetosphere. The atmosphere of Venus consists mainly of carbon dioxide, and, at the planet’s surface, is the densest and hottest of the atmospheres of the four terrestrial planets. With an atmospheric pressure at the planet's surface of about 92 times the sea level pressure of Earth and a mean temperature of 737 K (464 °C; 867 °F), the carbon dioxide gas at Venus's surface is in the supercritical phase of matter. Venus is shrouded by an opaque layer of highly reflective clouds of sulfuric acid, making it the planet with the highest albedo in the Solar System. It may have had water oceans in the past, but after these evaporated the temperature rose under a runaway greenhouse effect. The possibility of life on Venus has long been a topic of speculation but convincing evidence has yet to be found.

Observation: To the naked eye, Venus appears as a white point of light brighter than any other planet or star (apart from the Sun). The planet's mean apparent magnitude is −4.14 with a standard deviation of 0.31. The brightest magnitude occurs during crescent phase about one month before or after inferior conjunction. Venus fades to about magnitude −3 when it is backlit by the Sun. The planet is bright enough to be seen in broad daylight, but is more easily visible when the Sun is low on the horizon or setting. As an inferior planet, it always lies within about 47° of the Sun.

(Venus, credit: NASA)

Venus "overtakes" Earth every 584 days as it orbits the Sun. As it does so, it changes from the "Evening Star", visible after sunset, to the "Morning Star", visible before sunrise. Although Mercury, the other inferior planet, reaches a maximum elongation of only 28° and is often difficult to discern in twilight, Venus is hard to miss when it is at its brightest. Its greater maximum elongation means it is visible in dark skies long after sunset. As the brightest point-like object in the sky, Venus is a commonly misreported "unidentified flying object".

Tabulation:

Date and time:

The location of observation:

Longitude:

Latitude:

Sky condition:

Moon phase:

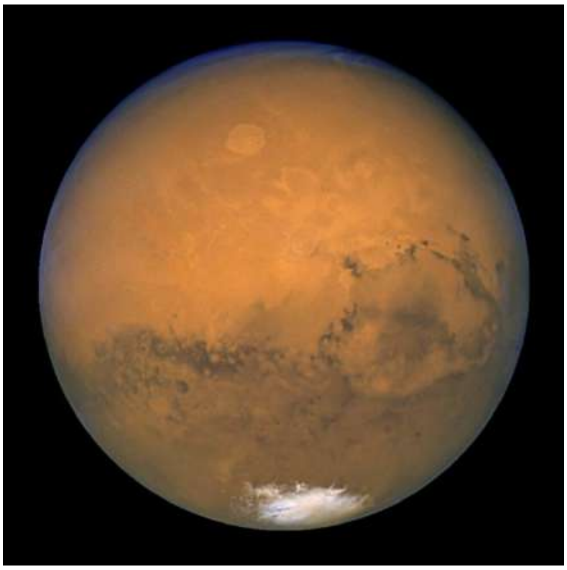
Time	Location of the object	Observational details

Discussion:

1. Discuss about what you see about the object.
2. Discuss weather condition and whether it affects the observation of the object.
3. What could be done to improve the observation (if possible).
4. Miscellaneous.

c) Mars

Mars is the fourth planet from the Sun and the second-smallest planet in the Solar System, only being larger than Mercury. In the English language, Mars is named for the Roman god of war. Mars is a terrestrial planet with a thin atmosphere (less than 1% that of Earth's), and has a crust primarily composed of elements similar to Earth's crust, as well as a core made of iron and nickel. Mars has surface features such as impact craters, valleys, dunes and polar ice caps. It has two small and irregularly shaped moons, Phobos and Deimos.



(Mars, credit: NASA)

Observation: The mean apparent magnitude of Mars is +0.71 with a standard deviation of 1.05. Because the orbit of Mars is eccentric, the magnitude at opposition from the Sun can range from about −3.0 to −1.4. The minimum brightness is magnitude +1.86 when the planet is near aphelion and in conjunction with the Sun. At its brightest, Mars (along with Jupiter) is second only to Venus in luminosity. Mars usually appears distinctly yellow, orange, or red. When farthest away from Earth, it is more than seven times farther away than when it is closest. Mars is usually close enough for particularly good viewing once or twice at 15-year or 17-year intervals. As Mars approaches opposition, it begins a period of retrograde motion, which means it will appear to move backwards in a looping curve with respect to the background stars. This retrograde motion lasts for about 72 days, and Mars reaches its peak luminosity in the middle of this interval.

The point at which Mars's geocentric longitude is 180° different from the Sun's is known as opposition, which is near the time of closest approach to Earth. The time of opposition can occur as much as 8.5 days away from the closest approach. The distance at close approach varies between about 54 and 103 million km due to the planets' elliptical orbits, which causes comparable variation in angular size. The most recent Mars opposition occurred on 13 October 2020, at a distance of about 63 million km. The average time between the successive oppositions of Mars, its synodic period, is 780 days; but the number of days between the dates of successive oppositions can range from 764 to 812.

Mars comes into opposition from Earth every 2.1 years. The planets come into opposition near Mars's perihelion in 2003, 2018 and 2035, with the 2020 and 2033 events being particularly close to perihelic opposition. Mars made its closest approach to Earth and maximum apparent brightness in nearly 60,000 years, 55,758,006 km (0.37271925 AU; 34,646,419 mi), magnitude −2.88, on 27 August 2003, at 09:51:13 UTC. This occurred when Mars was one day from opposition and about three days from its perihelion, making it particularly easy to see from Earth. The last time it came so close is estimated to have been on 12 September 57,617 BC, the next time being in 2287. This record approach was only slightly closer than other recent close approaches.

Tabulation:

Date and time:

The location of observation:

Longitude:

Latitude:

Sky condition:

Moon phase:

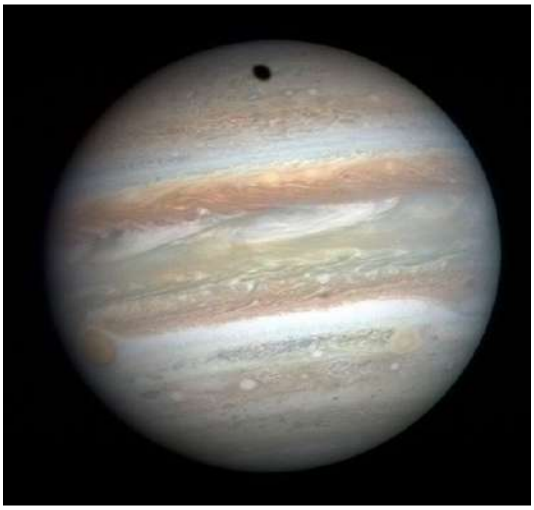
Time	Location of the object	Observational details

Discussion:

1. Discuss about what you see about the object.
2. Discuss weather condition and whether it affects the observation of the object.
3. What could be done to improve the observation (if possible).
4. Miscellaneous.

d) Jupiter

Jupiter is the fifth planet from the Sun and the largest in the Solar System. It is a gas giant with a mass more than two and a half times that of all the other planets in the Solar System combined, while being slightly less than one-thousandth the mass of the Sun. Jupiter is the third brightest natural object in the Earth's night sky after the Moon and Venus, and it has been observed since prehistoric times. It was named after Jupiter, the chief deity of ancient Roman religion.
Jupiter is primarily composed of hydrogen, but helium constitutes one-quarter of its mass and one-tenth of its volume. It probably has a rocky core of heavier elements, but (like the Solar System's other giant planets) lacks a well-defined solid surface. The ongoing contraction of Jupiter's interior generates more heat than the planet receives from the Sun. Because of its rapid rotation, the planet's shape is an oblate spheroid, having a slight but noticeable bulge around the equator. The outer atmosphere is divided into a series of latitudinal bands, with turbulence and storms along their interacting boundaries. A prominent result of this is the Great Red Spot, a giant storm which has been observed since at least 1831.



(Jupiter, credit: NASA)

Observation: Jupiter is usually the fourth brightest object in the sky (after the Sun, the Moon, and Venus), although at opposition Mars can appear brighter than Jupiter. Depending on Jupiter's position with respect to the Earth, it can vary in visual magnitude from as bright as −2.94 at opposition down to −1.66 during conjunction with the Sun. The mean apparent magnitude is −2.20 with a standard deviation of 0.33. The angular diameter of Jupiter likewise varies from 50.1 to 30.5 arc seconds. Favourable oppositions occur when Jupiter is passing through the perihelion of its orbit, bringing it closer to Earth. Near opposition, Jupiter will appear to go into retrograde motion for a period of about 121 days, moving backward through an angle of 9.9° before returning to prograde movement.

Because the orbit of Jupiter is outside that of Earth, the phase angle of Jupiter as viewed from Earth is always less than 11.5°; thus, Jupiter always appears nearly fully illuminated when viewed through Earth-based telescopes. It was only during spacecraft missions to Jupiter that crescent views of the planet were obtained. A small telescope will usually show Jupiter's four Galilean moons and the prominent cloud belts across Jupiter's atmosphere. A larger telescope with an aperture of 4–6 in (10.16–15.24 cm) will show Jupiter's Great Red Spot when it faces Earth.

Tabulation:

Date and time:

The location of observation:

Longitude:

Latitude:

Sky condition:

Moon phase:

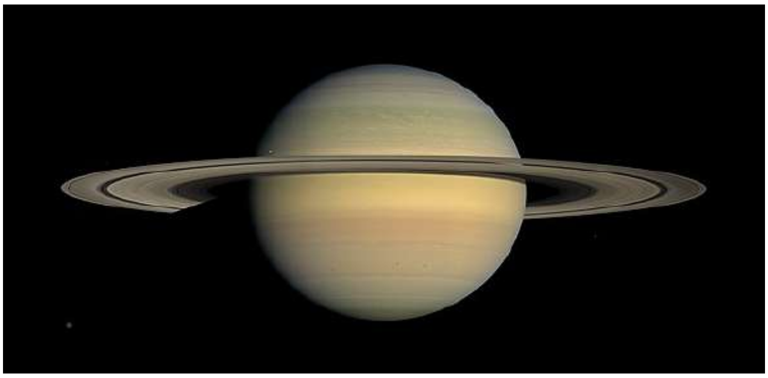
Time	**Location of the object**	**Observational details**

Discussion:
1. Discuss about what you see about the object.
2. Discuss weather condition and whether it affects the observation of the object.
3. What could be done to improve the observation (if possible).
4. Miscellaneous.

e) Saturn

Saturn is the sixth planet from the Sun and the second-largest in the Solar System, after Jupiter. It is a gas giant with an average radius of about nine and a half times that of Earth. It has only one-eighth the average density of Earth, but is over 95 times more massive.
Saturn's interior is most likely composed of a rocky core, surrounded by a deep layer of metallic hydrogen, an intermediate layer of liquid hydrogen and liquid helium, and finally, a gaseous outer layer. Saturn has a pale yellow hue due to ammonia crystals in its upper

atmosphere. An electrical current within the metallic hydrogen layer is thought to give rise to Saturn's planetary magnetic field, which is weaker than Earth's, but which has a magnetic moment 580 times that of Earth due to Saturn's larger size. Saturn's magnetic field strength is around one-twentieth of Jupiter's. The outer atmosphere is generally bland and lacking in contrast, although long-lived features can appear. Wind speeds on Saturn can reach 1,800 kilometres per hour (1,100 miles per hour), higher than on Jupiter but not as high as on Neptune.



(Saturn, credit: NASA)

Observation: Saturn is the most distant of the five planets easily visible to the naked eye from Earth, the other four being Mercury, Venus, Mars and Jupiter. (Uranus, and occasionally 4 Vesta, are visible to the naked eye in dark skies.) Saturn appears to the naked eye in the night sky as a bright, yellowish point of light. The mean apparent magnitude of Saturn is 0.46 with a standard deviation of 0.34. Most of the magnitude variation is due to the inclination of the ring system relative to the Sun and Earth. The brightest magnitude, −0.55, occurs near in time to when the plane of the rings is inclined most highly, and the faintest magnitude, 1.17, occurs around the time when they are least inclined. It takes approximately 29.5 years for the planet to complete an entire circuit of the ecliptic against the background constellations of the zodiac. Most people will require an optical aid (very large binoculars or a small telescope) that magnifies at least 30 times to achieve an image of Saturn's rings in which clear resolution is present. When Earth passes through the ring plane, which occurs twice every Saturnian year (roughly every 15 Earth years), the rings briefly disappear from view because they are so thin. Such a "disappearance" will next occur in 2025, but Saturn will be too close to the Sun for observations.

Saturn and its rings are best seen when the planet is at, or near, opposition, the configuration of a planet when it is at an elongation of 180°, and thus appears opposite the Sun in the sky. A Saturnian opposition occurs every year—approximately every 378 days—and results in the planet appearing at its brightest. Both the Earth and Saturn orbit the Sun on eccentric orbits, which means their distances from the Sun vary over time, and therefore so do their distances from each other, hence varying the brightness of Saturn from one opposition to the next. Saturn also appears brighter when the rings are angled such that they are more visible. For example, during the opposition of 17 December 2002, Saturn appeared at its brightest due to a favorable orientation of its rings relative to the Earth, even though Saturn was closer to the Earth and Sun in late 2003.

From time to time, Saturn is occulted by the Moon (that is, the Moon covers up Saturn in the sky). As with all the planets in the Solar System, occultations of Saturn occur in "seasons". Saturnian occultations will take place monthly for about a 12-month period, followed by about a five-year period in which no such activity is registered. The Moon's orbit is inclined by several degrees relative to Saturn's, so occultations will only occur when Saturn is near one of the points in the sky where the two planes intersect (both the length of Saturn's year and the 18.6-Earth year nodal precession period of the Moon's orbit influence the periodicity).

Tabulation:

Date and time:

The location of observation:

Longitude:

Latitude:

Sky condition:

Moon phase:

Time	**Location of the object**	**Observational details**

Discussion:

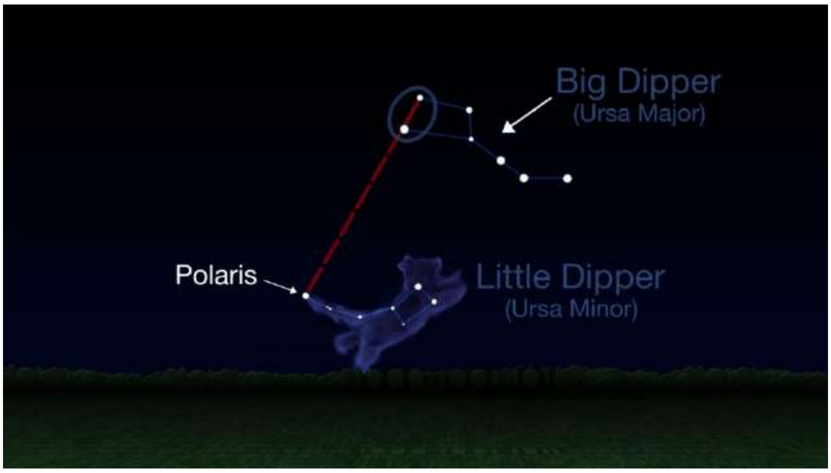
1. Discuss about what you see about the object.
2. Discuss weather condition and whether it affects the observation of the object.
3. What could be done to improve the observation (if possible).
4. Miscellaneous.

f) North Star or Pole Star

Polaris is a star in the northern circumpolar constellation of Ursa Minor. It is designated α Ursae Minoris (Latinized to *Alpha Ursae Minoris*) and is commonly called the North Star or Pole Star. With an apparent magnitude that fluctuates around 1.98, it is the brightest star in the constellation and is readily visible to the naked eye at night. The position of the star lies less than 1° away from the north celestial pole, making it the current northern pole star. The stable position of the star in the Northern Sky makes it useful for navigation.

As the closest Cepheid variable its distance is used as part of the cosmic distance ladder. The revised *Hipparcos* stellar parallax gives a distance to Polaris of about 433 light-years (133 parsecs), while the successor mission *Gaia* gives a distance of about 448 light-years (137 parsecs). Calculations by other methods vary widely.

Although appearing to the naked eye as a single point of light, Polaris is a triple star system, composed of the primary, a yellow supergiant designated Polaris Aa, in orbit with a smaller companion, Polaris Ab; the pair is in a wider orbit with Polaris B. The outer pair AB were discovered in August 1779 by William Herschel, where the 'A' refers to what is now known to be the Aa/Ab pair.



Observation: The North Star isn't the brightest star in the sky, but it's usually not hard to spot, even from the city. If you're in the Northern Hemisphere, it can help you orient yourself and find your way, as it's located in the direction of true north (or geographic north, as opposed to magnetic north).

Locating Polaris is easy on any clear night. Just find the Big Dipper. The two stars on the end of the Dipper's "cup" point the way to Polaris, which is the tip of the handle of the Little Dipper, or the tail of the little bear in the constellation Ursa Minor.

Tabulation:

Date and time:

The location of observation:

Longitude:

Latitude:

Sky condition:

Moon phase:

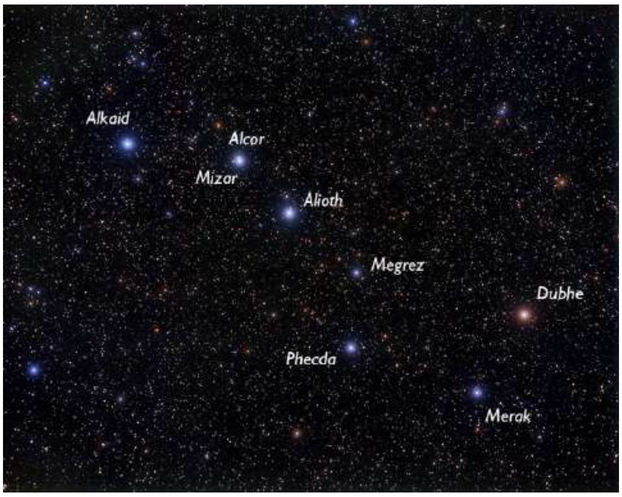
Time	**Location of the object**	**Observational details**

Discussion:

1. Discuss about what you see about the object.
2. Discuss weather condition and whether it affects the observation of the object.
3. What could be done to improve the observation (if possible).
4. Miscellaneous.

f) The Big Dipper

The Big Dipper is a large asterism consisting of seven bright stars of the constellation Ursa Major;six of them are of second magnitude and one, Megrez (δ), of third magnitude. Four define a "bowl" or "body" and three define a "handle" or "head". It is recognized as a distinct grouping in many cultures. The North Star (Polaris), the current northern pole star and the tip of the handle of the Little Dipper (Little Bear), can be located by extending an imaginary line through the front two stars of the asterism, Merak (β) and Dubhe (α). This makes it useful in celestial navigation.



Observation: The Big Dipper is one of the easiest star patterns to locate in Earth's sky. It's visible just about every clear night in the Northern Hemisphere, looking like a big dot-to-dot of a kitchen ladle. As Earth spins, the Big Dipper and its sky neighbor, the Little Dipper, rotate around the North Star, also known as Polaris. From the northern part of the Northern Hemisphere, the Big and Little Dippers are in the sky continuously, always above your horizon, circling endlessly around Polaris. Given an unobstructed horizon, latitudes north of the 35th parallel (the approximate location of the Mediterranean Sea and Tennessee's southern border) can expect to see the Big Dipper at any hour of the night for all days of the year.

Tabulation:

Date and time:

The location of observation:

Longitude:

Latitude:

Sky condition:

Moon phase:

Time	Location of the object	Observational details

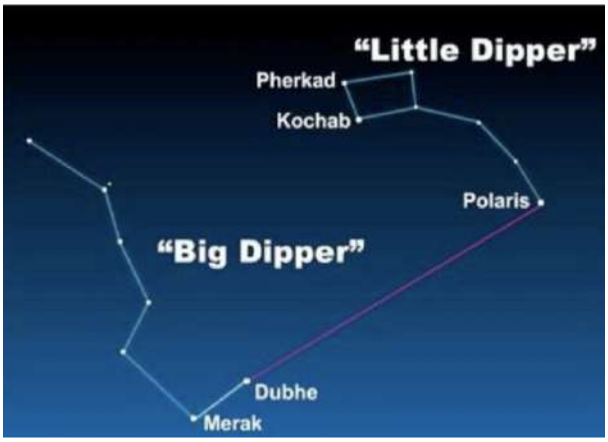
Discussion:

1. Discuss about what you see about the object.
2. Discuss weather condition and whether it affects the observation of the object.
3. What could be done to improve the observation (if possible).
4. Miscellaneous.

g) The Little Dipper

Ursa Minor (Latin: 'Lesser Bear', contrasting with Ursa Major), also known as the Little Bear, is a constellation located in the far northern sky. As with the Great Bear, the tail of the Little Bear may also be seen as the handle of a ladle, hence the North American name, Little Dipper: seven stars with four in its bowl like its partner the Big Dipper. Ursa Minor was one of the 48 constellations listed by the 2nd-century astronomer Ptolemy, and remains one of the 88 modern constellations. Ursa Minor has traditionally been important for navigation, particularly by mariners, because of Polaris being the north pole star.

Polaris, the brightest star in the constellation, is a yellow-white supergiant and the brightest Cepheid variable star in the night sky, ranging in apparent magnitude from 1.97 to 2.00. Beta Ursae Minoris, also known as Kochab, is an aging star that has swollen and cooled to become an orange giant with an apparent magnitude of 2.08, only slightly fainter than Polaris. Kochab and 3rd-magnitude Gamma Ursae Minoris have been called the "guardians of the pole star" or "Guardians of The Pole". Planets have been detected orbiting four of the stars, including Kochab. The constellation also contains an isolated neutron star—Calvera—and H1504+65, the hottest white dwarf yet discovered, with a surface temperature of 200,000 K.



Observation: Little Dipper is *circumpolar* – always above the horizon – as far south as the Tropic of Cancer (23.5 degrees north latitude).

If you can spot the Big Dipper, then you're on your way to finding the Little Dipper and the North Star, Polaris, too.
Just remember the old saying *spring up and fall down*. On spring and summer evenings in the Northern Hemisphere, the Big Dipper shines at its highest in the evening sky. On autumn and winter evenings, the Big Dipper sweeps closer to the horizon.

Tabulation:

Date and time:

The location of observation:

Longitude:

Latitude:

Sky condition:

Moon phase:

Time	Location of the object	Observational details

Discussion:
1. Discuss about what you see about the object.
2. Discuss weather condition and whether it affects the observation of the object.
3. What could be done to improve the observation (if possible).
4. Miscellaneous.

h) Betelgeuse

Betelgeuse is a red supergiant of spectral type M1-2 and one of the largest stars visible to the naked eye. It is usually the tenth-brightest star in the night sky and, after Rigel, the second-brightest in the constellation of Orion. It is a distinctly reddish, semiregular variable star whose apparent magnitude, varying between +0.0 and +1.6, has the widest range displayed by any first-magnitude star. At near-infrared wavelengths, Betelgeuse is the brightest star in the night sky. Its Bayer designation is α Orionis, Latinised to Alpha Orionis and abbreviated Alpha Ori or α Ori.

Observation: Betelgeuse appears as a bright orange/red star in the upper left ‘shoulder’ of the constellation Orion. This red supergiant-type star is one of the largest you can see with your naked eye.

It is one of the easiest stars to identify in the night sky thanks to its distinctive orange/red color, and position within Orion. During the month of December, the Orion constellation is visible from almost every inhabited region on Earth.

Tabulation:

Date and time:

The location of observation:

Longitude:

Latitude:

Sky condition:

Moon phase:

Time	**Location of the object**	**Observational details**

Discussion:

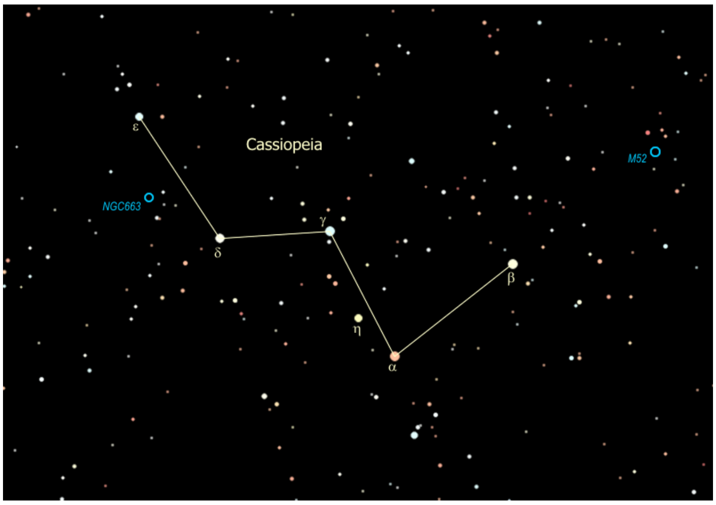
1. Discuss about what you see about the object.
2. Discuss weather condition and whether it affects the observation of the object.
3. What could be done to improve the observation (if possible).
4. Miscellaneous.

i) Cassiopeia

Cassiopeia is a constellation in the northern sky named after the vain queen Cassiopeia, mother of Andromeda, in Greek mythology, who boasted about her unrivaled beauty. Cassiopeia was one of the 48 constellations listed by the 2nd-century Greek astronomer Ptolemy, and it remains one of the 88 modern constellations today. It is easily recognizable due to its distinctive 'W' shape, formed by five bright stars.
Cassiopeia is located in the northern sky and from latitudes above 34°N it is visible year-round. In the (sub)tropics it can be seen at its clearest from September to early November, and at low southern, tropical, latitudes of less than 25°S it can be seen, seasonally, low in the North.

Observation: The constellation Cassiopeia the Queen can be found high in the northeast on October evenings, not far from Polaris, the North Star. At any time of year, you can use the Big Dipper to find Cassiopeia. These two-star formations are like riders on opposite side of a Ferris wheel. They’re part of a great spinning wheel of stars seen moving counterclockwise around Polaris, the North Star, once each day. As Cassiopeia rises upward, the Big Dipper plunges downward, and vice versa.

Some of you know how to star-hop to Polaris, the North Star, by using the Big Dipper’s pointer stars, as displayed on the sky chart below. Because the Big Dipper’s handle and Cassiopeia shine on opposite sides of Polaris, an imaginary line from any star on the Big Dipper handle through Polaris reliably points to Cassiopeia.



Tabulation:

Date and time:

The location of observation:

Longitude:

Latitude:
Sky condition:

Moon phase:

Time	Location of the object	Observational details

Discussion:

1. Discuss about what you see about the object.
2. Discuss weather condition and whether it affects the observation of the object.
3. What could be done to improve the observation (if possible).
4. Miscellaneous.

2. Study of Movement of Moon Between Rise to Set Time.

If we first think about the Moon in relation to the Earth, we can explain how it appears to travel across the sky over the course of a night, and why it rises and falls at different times and in different locations.

The first bit is easy. Just like the Sun and the night time stars, the Moon's apparent rising in the east and setting in the west each day is not from the Moon's orbit around the Earth, it's from the Earth spinning.

The lunar orbit is slower and harder to see – but you can still spot it. By looking at where the Moon is in relation to stars in the background one night, and then comparing to where it is several hours later or on the next night, you'll notice it has moved east. This movement is from the Moon's orbit, which takes 27 days, 7 hours and 43 minutes to go full circle.

It causes the Moon to move 12–13 degrees east every day. This shift means Earth has to rotate a little longer to bring the Moon into view, which is why moonrise is about 50 minutes later each day. As it rises at a later time, the Moon appears in a different part of the sky.

Method

The moon changes its locations in sky with time. We have to measure elevation and azimuth of Moon with constant interval throughout the time between rise to set of the Moon. It will rise in East and will set in West.

One need to plot the variation of elevation and azimuth with time throughout the rise to set time of the Moon.

Time (IST)	Elevation	Azimuth

Discussion

1. Discuss the observational condition of the day.
2. Discuss the Moon phase.
3. Discuss the weather condition.

3. Study of Movement of a Star in Sky between Rise to Set of the Planet.

We know that Earth is not the center of the universe—let alone the Solar System—but looking at the sky, it's easy to get confused. Stars appear to be rising and setting, as well as the planets, Moon and the Sun. And with more precise instruments, we can see some stars appearing to move back and forth relative to other ones.

(Star trails over Lake Minnewanka in Alberta, Canada. Credit: Jack-Fusco.)

As we'll see below, we can explain those movements through the Earth's rotation and movement through its orbit. But stars also have their own proper motion through space. So when we say that stars "move", it could be because of the Earth, because of their own movements, or because of both!

The Earth takes roughly 24 hours to spin on its axis, moving from east to west. And if you watch the sky over a few hours in most locations on Earth, you can see the same thing happening: stars rising in the east, and setting in the west. There are some exceptions to this rule, however:

- Stars that are close to the Earth's axis of rotation—what we call the north and the south pole—rotate around the poles. If the pole's location is far enough above the horizon, some stars never set. They just keep spinning.
- If your geographical location happens to be close to the pole, most stars will be rotating around the pole and very few will rise and set. (And in a trick of geometry, it will be hard to see the Sun, moon and planets since their path in the sky is at 23.5 degrees—the same as Earth's tilt. This is why the poles have months of darkness, because the Sun doesn't always shine there.)

So, we've covered the Earth's rotation, but we've neglected to mention its orbit around the Sun. It takes us about 365 days to make a full trip. As we move along in space, some curious effects occur. Consider the famous Mars mystery; astronomers used to be puzzled as to why the planet appeared to stop its movement against the background stars, go backwards and then go forwards again. Turns out it was Earth in its orbit "catching up" to the more distant Mars and passing it by.

(Credit: Cory Schmitz)

At opposite ends of our orbit—say, in winter and summer—we can even see some stars appearing to shift against the background. If you picture the Earth in its orbit around the Sun, recall that we orbit about 93 million miles (150 million kilometers) from our closest neighbor. So at opposite ends of the orbit, Earth's position is double that—186 million miles (300 million kilometers).

Here's where it gets interesting. Imagine you're doing laps around a baseball field, looking at a building about a mile (1.6 kilometers) away. That building will appear to shift positions as you move around the track. The same thing happens when the Earth moves around in its orbit. Some of the closer stars can be seen moving back and forth across the background. We call this effect parallax and we can use it for stars that are as far away as about 100 light-years. We can actually calculate their distance using some geometry.

So we've covered ways the stars "move" due to the Earth's orbit. But stars can move for other reasons as well. Maybe we're observing a binary system where two stars are orbiting around each other. Maybe the stars are embedded in a galaxy that is itself rotating. Maybe the star is moving due to the expansion of the Universe, which gradually stretches distances between objects.

But stars also have their own motion in space—called proper motion—that is independent of these phenomena. Why is the star moving? Simply put, it's because of gravity—because they are moving around the center of their galaxy, for example. Gravity makes every object in space move. But as most stars are far away from us and space is so big, that proper motion is very small in a human lifetime. The star with the highest proper motion is Barnard's Star. It moves 10.3 seconds of arc per year, meaning it takes about 180 years for it to move the diameter of the full Moon in our sky.

Method

All stars change their locations in sky with time. We have to measure elevation and azimuth of a selected star with constant interval throughout the night. All the stars will rise in East and will set in West.

One need to plot the variation of elevation and azimuth with time throughout the rise to set time of the Moon.

Time (IST)	Elevation	Azimuth

Discussion

1. Discuss the observational condition of the day.
2. Discuss the weather condition.

4. Study of Movement of a Planet in Sky Between Rise to Set

The planets also move around the Sun. Because of this and also because of the reflex motion from the Earth's revolution, the planets also appear to move with respect to the stars.

The qualitative motions of the planets can be understood if one recognizes that:

- All of the planets move around the Sun in roughly the same plane
- All of the planets move around the Sun in the same direction
- The planets which are nearer to the Sun move faster than those which are farther away

Method

All planets change their locations in sky with time. We have to measure elevation and azimuth of a particular planet with constant interval throughout the time between rise to set of the planet in night sky. It will rise in East and will set in West.

One need to plot the variation of elevation and azimuth with time throughout the rise to set time of the planet.

Time (IST)	Elevation	Azimuth

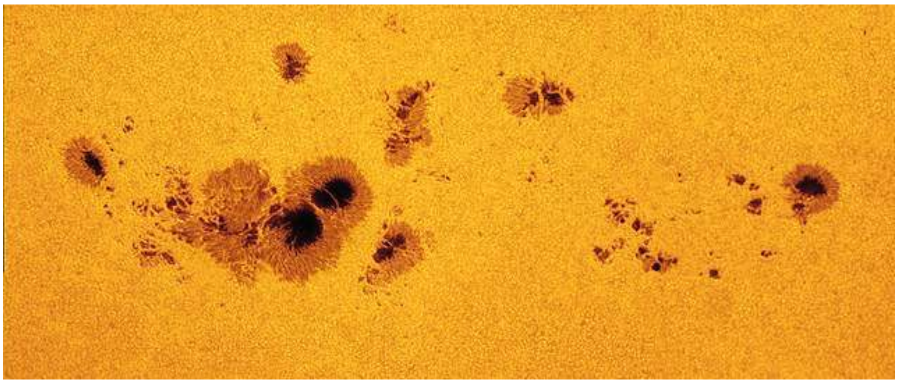
Discussion

1. Discuss the observational condition of the day.
2. Discuss the weather condition.

5. Identify Sun Spots with a Solar-filter or a Mirror

Sunspots are phenomena on the Sun's photosphere that appear as temporary spots that are darker than the surrounding areas. They are regions of reduced surface temperature caused by concentrations of magnetic flux that inhibit convection. Sunspots appear within active regions, usually in pairs of opposite magnetic polarity. Their number varies according to the approximately 11-year solar cycle.

Individual sunspots or groups of sunspots may last anywhere from a few days to a few months, but eventually decay. Sunspots expand and contract as they move across the surface of the Sun, with diameters ranging from 16 km to 160,000 km. Larger sunspots can be visible from Earth without the aid of a telescope. They may travel at relative speeds, or proper motions, of a few hundred meters per second when they first emerge.



Observation: The Sun is also the only celestial object hazardous to the observer. Without proper protection, even a glimpse of it through a telescope or binoculars can burn the eye's retina and leave a permanent blind spot.

There are two ways to look at the Sun safely: by *direct viewing*, with a proper filter over the front of the telescope, or by *projecting* the Sun's image onto a piece of paper.

They protect the eye against both visible and invisible radiations and the telescope itself against heat. These *aperture filters* have made every other light-reducing device obsolete as far as the ordinary amateur is concerned.

Aperture filters come in two kinds. The most economical is made of metallized Mylar plastic, which usually turns the Sun blue. (Do *not* stretch the Mylar to remove wrinkles.) Metal-on-glass filters leave the Sun with a more natural tint, are more durable, and cost more.

In either case, the best filters have both sides of the Mylar or glass metallized allowing you to look at the sun. This keeps the inevitable tiny scratches and pinholes in a single coating from letting sunlight into the telescope, where it would reduce image contrast and possibly threaten the eye when you look at the sun. Hold the filter up to the Sun. If bright pinpoints show through, they should be touched out with opaque paint. If the flaws are many or large, the filter should be rejected.

Be sure to attach the filter securely to the front of the telescope so wind or a careless finger can't dislodge it when you look at the Sun!

The projection method is preferred by many solar observers — see "Sketching Sunspots" for an example of the method's advantages.

For a quick first look at the sun by this technique, hold a white card or paper a foot or two behind the eyepiece of a telescope or a pair of binoculars on a tripod. The card must be shaded from direct sunlight. Focus until the Sun's limb appears sharpest. Almost as much detail will be visible in the projected image as when the Sun is viewed directly through an aperture filter.

For more than a quick look at the sun, you'll need a *projection screen* attached to the telescope to hold the paper. Such screens are sometimes supplied with small refractors. You can make your own (or better yet a projection box, to improve contrast by keeping daylight off the paper) by experimenting with cardboard, wooden dowels, bolts, and plywood. Plan the distance from eyepiece to screen to be $107d/(m - 1)$, where m is the telescope's magnification and d is the diameter you want the Sun's image to be.

Tabulation:

Date and time:

The location of observation:

Longitude:

Latitude:

Sky condition:

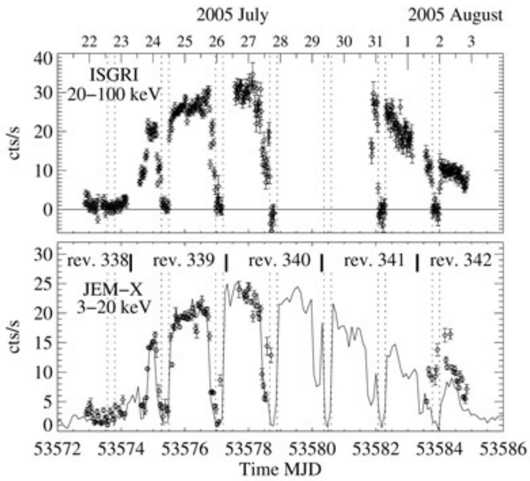
1. Take a picture of the Sun with sunspots.
2. Study number of sunspots and their nature.
3. Check whether there is any evolution features in sunspot(s) within the observation run.

Discussion:

1. Discuss about the nature of the Sunspots
2. Discuss weather condition and whether it affects the observation of sunspots.
3. Discuss about the safety precautions you have taken to avoid direct Sunlight in eyes.
4. Miscellaneous.

5. Study of Lightcurve of Astronomical Sources in Different Energy Bands.

In astronomy, a light curve is a graph of light intensity of a celestial object or region as a function of time, typically with the magnitude of light received on the y axis and with time on the x axis. The light is usually in a particular frequency interval or band. Light curves can be periodic, as in the case of eclipsing binaries, Cepheid variables, other periodic variables, and transiting extrasolar planets, or aperiodic, like the light curve of a nova, a cataclysmic variable star, a supernova or a microlensing event or binary as observed during occultation events. The study of the light curve, together with other observations, can yield considerable information about the physical process that produces it or constrain the physical theories about it.



Method:
For different satellites the light curve generation procedure is different. Check corresponding manual of a given satellite to find necessary software and commands to generate light curves.

You have to draw the light curve of a given instrument from a selected satellite and produce the light curve for verification.

Tabulation: Record following information from the provided astronomical data.

1. Name of the source
2. Nature of the source
3. Coordinate of the source
4. Name of the satellite
5. Name of the instrument

Also store the lightcurve for verification.

Discussion:
1. Discuss what you learnt from the lightcurve.
2. Compare lightcurves in different energy bands.

6. Study of Power Density Spectrum of Different Astronomical Sources

The **power spectral density** (PSD) or **power spectrum** provides a way of representing the distribution of signal frequency components which is easier to interpret visually than the complex DFT. As the term suggests, it represents the proportion of the total signal power contributed by each frequency component of a voltage signal ($P = V^2$IR). It is computed from the DFT as the mean squared amplitude of each frequency component, averaged over the n samples in the digitized record. However, since only $n/2$ frequency components are unique, the two halves of the DFT are combined (doubling the power of each component) and plotted as the lower $k = 1 \ldots n/2+1$ components

$$\mathrm{PSD}(k) = \frac{2\,di}{n^2}\left((Y_{\mathrm{real}}(k))^2 + (Y_{\mathrm{imag}}(k))^2\right)$$

For astronomical sources, scientists use PSD to study different periodical and pseudo-periodical features from the light curve of an astronomical source.

Method: After creating cleaned and selected data files, we're now ready to put them into powspec, the xronos task that generates a power density spectrum. At this point, it's worth repeating that this sort of temporal analysis should not be thought of as a simple recipe. Rather, it's an analysis technique that requires the user to make several choices based on the scientific priorities of the investigation and on the properties of the source.
This example gives the most convenient and common usage of powspec, but note that the tool has a long and comprehensive help file ("fhelp powspec") which the advanced user will wish to study. First type "powspec", then:

1. **`Ser. 1 filename +options (or @file of filenames +options)[file1]:`** Here, give the name of the one of the data files you've prepared, e.g. `good_01.se`. But note:

    - You can also enter more than one datafile here - either by name or via an ASCII list prefaced with an @-sign). However, there are two good reasons to be cautious. The first is speed: 12 minutes of data at 122-microsecond resolution - i.e. 6 million points - will take powspec an hour to work through on a Sparc10. The second is scientific: calculating a power spectrum over data gaps will introduce spurious signals which may or may not be important.

    - If you are reading Single-Bit or Binned data directly into powspec, then the string `VY2` should follow each filename (the same is true if the filenames are in an ASCII list). This tells xronos which column in the FITS file to use, e.g.

    ```
    good_singlebit.sa VY2
    ```

    In the case of Event files, `VY2` isn't needed.

2. **`Name of the window file ('-' for default window)[]:`** Type in a hyphen for the default window (experienced users can supply additional time filtering here - see 'fhelp xronwin' for help on how to create a window file).

   [If you get a message saying that the `defaults_win.wi` file is not found, this means you don't have the xronos `XRDEFAULTS` environment variable set correctly. You'll need to set it by issuing a command like:

   ```
      setenv XRDEFAULTS
   '/ftools/SUN/develop/xronos/defaults/'
   ```

   With the path correctly set for your ftools installation, run powspec again. Be careful: the last / *is* important.]

3. **`Newbin Time or negative rebinning:`** To obtain a power spectrum extending up to 2000 Hz - probably a good idea if you're hunting for kHz QPO - your bins should be about 1/4096 seconds, i.e. 250 microseconds (The Nyquist frequency = 1/2*newbin.) Although powspec can accept arbitrary newbin sizes, it's better to specify an integral factor by which the original resolution is to be multiplied. For example, in the case of the Event configuration `E_62us_64M_0_1s_L1R1`, the time resolution is 1/2**14 seconds. So, to obtain bins of 250 microseconds, the original resolution should be multiplied by a factor of four. To do this in powspec, give the newbin size as -4. Note that powspec prints the time resolution - but often truncated - on the screen after reading the input file. Look for a line like:

   ```
      Bin Time (s) ......   0.6104E-04
   ```

4. **`Number of Newbins/Interval:`** Powspec divides data into "intervals" over which it calculates individual power spectra. The final power spectrum is the average of these. Choosing the interval size is scientific question: the longer the interval, the larger the frequency range of the power spectrum. But the shorter the interval, the lower the noise. If, for example, you're not interested in frequencies below about 1 Hz, then your intervals needn't be longer than 1 s, that is, 4096 newbins of 250 microseconds.

5. **`Number of Intervals/Frame:`** As you probably want to create the summed power spectrum for the whole dataset, make sure that the number you enter is equal to or bigger than the number given for "default intervals per frame" supplied by the program two lines above this prompt.

   Make a note of the number you enter here, known to the code as `NINTFM`. It is the number of 'processing intervals' the program will later work through before giving a result.

6. **`Rebin results?:`** You should definitely do this, or your power spectrum will be very noisy at high frequencies. For kHz QPO searches, geometric rebinning of -1.005

is good. If you're more interested in the 10-100 Hz range, use -1.01 or even -1.02. Experimentation will show what level of binning is ideal for your purposes.

7. After this you'll go through a series of prompts for: output filenames (powspec will add `.fps` to whatever you specify); whether you want to plot; and the name of the plotting device. (If you say "no" to the "Want to Plot" question, the data will still be saved in the file for your later use.

Powspec will now trundle along, performing `NINTFM` fast Fourier transforms, writing to the screen the number and start time of the data segment transformed, plus the data maximum, minimum, variance etc.

If you answered "yes" to the plot question, the power spectrum will appear on your screen when the number crunching completes, and will leave you with a `PLT>` prompt. It only writes the data to a file once you exit the plot by typing "q" - in other words, don't control-Z out of the plot interface, or you'll lose everything.

If you're analyzing LMXB data and searching for high-frequency QPO, you'll look with interest at the region of the power spectrum between (say) 300 and 1200 Hz. You may also see a sloping low frequency red noise component, or QPO in the 1-60 Hz range.

Plotting your Powspec Output to Find QPOs

Once the file is made and you've exited powspec, you can plot the data in the output.fps file by typing "fplot output.fps" and giving the following columns for the axis names:

```
X Axis Parameter[error]: FREQUENCY[XAX_E]
Y Axis Parameter[error]: POWER[ERROR]
```

You'll probably want to look at the plot in log-log space:

```
PLT> log x
PLT> log y
PLT> p
```

If you discover one or more QPO peaks, you'll want to do some fitting to determine some scientifically interesting parameters. The simplest way to do this is to plot the data using FPLOT and the do your fits within the PLT interface. There is extensive help on how to do this in the plotting recipe and also within the PLT interface itself (just type "help" at the `PLT>` prompt) but, stated briefly, the steps you'll do are as follows:

1. Limit your plot to the frequency range of interest, using 'r x {lowfreq} {highfreq}
2. Fit a model to the 'background' or continuum power spectrum: 'model pow' or 'model cons linr' might be good first choices.
3. Add a Lorentzian to this model, e.g. 'model pow lore'. The three parameters of the Lorentzian are LC, the line center (centroid frequency of the QPO); LW, the line width; and LN, the line normalization.

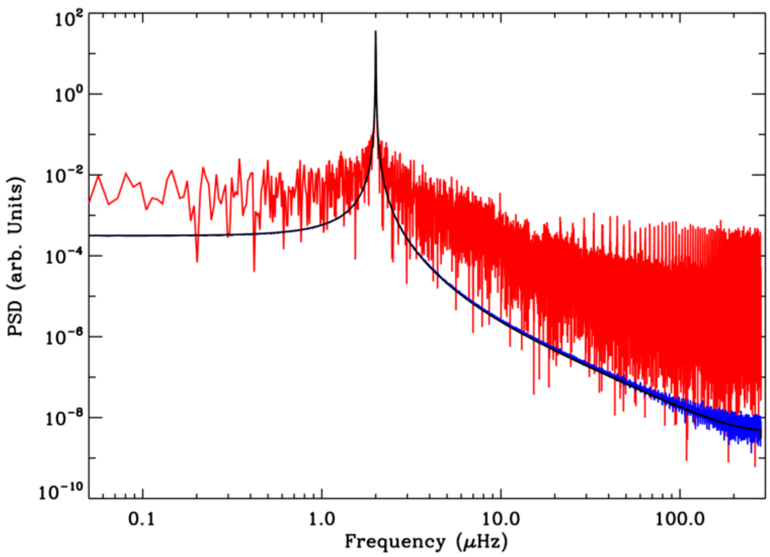
4. When you're happy with the fit you can determine the formal error on the fit using the UNCER command.
5. The centroid frequency and line width can be used in your IAU Circular 'as is'. To get the rms amplitude of the QPO, work out the integral of the Lorenzian:

```
I = pi*LN*LW/2
```

Finally, divide this by the mean count rate of the source, take the square root, and multiply by 100 to get this as a percentage, i.e.

```
rms amplitude = 100*sqrt( I/mean )
```

Result: Draw the PDS from the given light curve using above mentioned method.



Discussion:

1. Discuss what you can learn from the PSD.