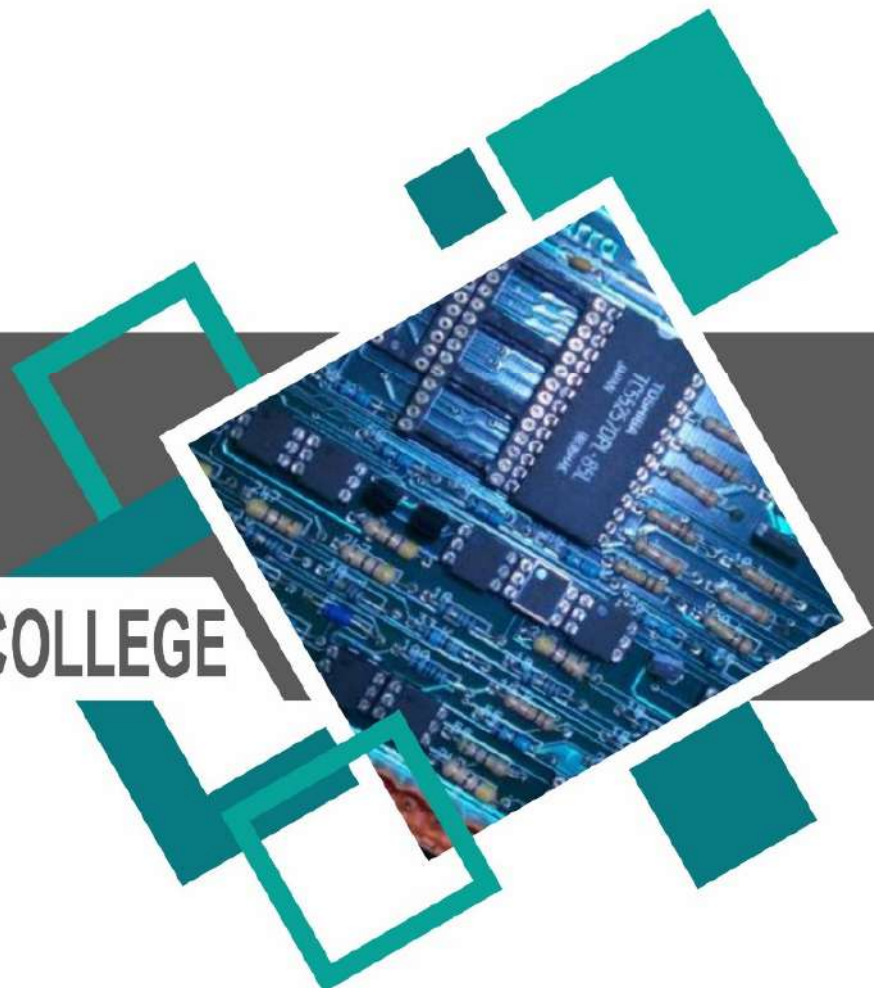


B.Sc. PHYSICS LAB MANUAL  
6th Semester



Prepared By  
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Physics

**MIDNAPORE CITY COLLEGE**



**Course No: C13P:**  
**Electromagnetic Theory (Lab)**  
**Credit: 2**

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## 1. To verify the law of Malus for plane polarized light.

### Objective

- The plane of polarization of a linear, polarized laser beam is to be determined.
- The intensity of the light transmitted by the polarization filter is to be determined as a function of the angular position of the filter.
- Malus' law must be verified.

### Theory

Linear, polarized light passes through a polarization filter. Transmitted light intensity is determined as a function of the angular position of the polarization filter.



Let AA' be the Polarization planes of the analyzer in Fig. 2. If linearly polarized light, the vibrating plane of which forms an angle  $\phi$  with the polarization plane of the filter, impinges on the analyzer, only the part

$$E_A = E_0 \cdot \cos \theta$$

will be transmitted. As the intensity  $I$  of the light wave is proportional to the square of electric field intensity vector  $E$ , the following relation (Malus' law) is obtained

$$I_A = I_0 \cdot \cos^2 \phi$$

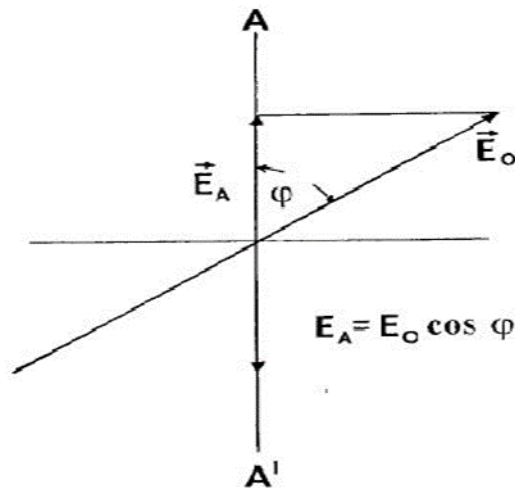


Fig. 2: Geometry for the determination of transmitted light intensity.

Fig.3 shows the photo cell current after background correction (this is a measure for the transmitted light intensity) as a function of the angular position of the polarization plane of the analyzer. The intensity peak for  $\varphi = 50^\circ$  shows that the polarization plane of the emitted laser beam has already been rotated by this angle against the vertical.

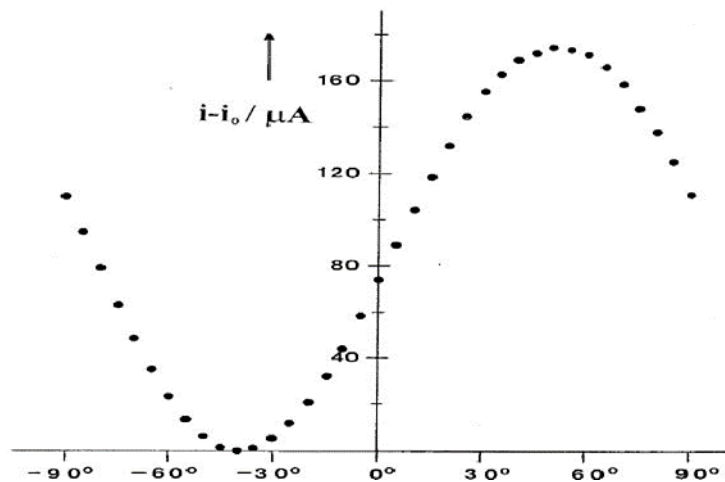


Fig.3: Corrected photo cell current as a function of the angular position of the polarization plane of the analyzer.

Fig.4 shows the normalized and corrected photo cell currents as a function of the angular position of the analyzer. Malus's law is verified by the initial line's  $45^\circ$  slope (Note: to determine Malus' line in Fig. 4, an angular setting of  $50^\circ$  of the analyzer must be considered for  $\varphi = 0^\circ$ ).

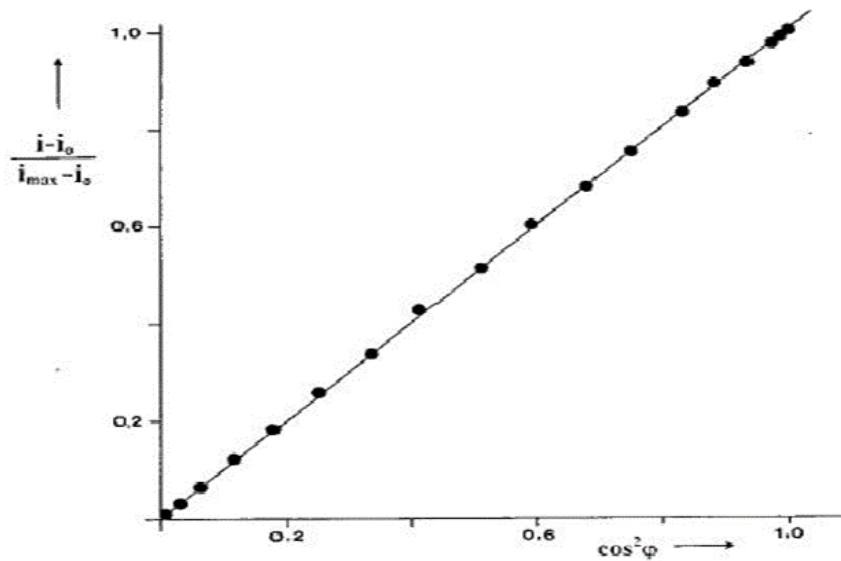


Fig .4: Normalized photo cell current as a function of  $\cos^2 \varphi$

### Apparatus:

### Experimental set-up

The experiment is set up according to Fig. 1. It must be made sure that the photocell is totally illuminated when the polarization filter is set up. If the experiment is carried out in a non darkened room, the disturbing background current  $i_0$  must be determined with the laser switched off and this must be taken into account during evaluation. The laser should be allowed to warm up for about 30 minutes to prevent disturbing intensity fluctuations. The polarization filter is then rotated in steps of  $5^\circ$  between the filter positions  $\pm 90^\circ$  and the corresponding photo cell current (most sensitive direct current range of the digital multimeter) is determined.

### Observations

- 1- Plot the experimental curve for the law of Malus  $I_A = I_0 \cdot \cos^2 \varphi$  on the same graph and calculate  $I$  as a percentage of  $I_0$ .

(I)	( $I_0$ )	$\Theta$

- 2- Describe in your own words what is mean by and draw a picture of A- Unpolarized light. B- Linearly polarized light.
- 3- Describe in words and figures what a transverse wave is and what a longitudinal wave is. Is laser transverse wave or longitudinal wave?
- 4- Discusses how intensity is become when the linearly polarized and un polarized light are passes through the polarizer filter.

## 2. To determine the specific rotation of sugar solution using Polarimeter.

**Objective:** To determine the specific rotation of a cane sugar solution.



Figure 1: Left-panel: Polarimeter instrument and its set-up. Right-panel: Place of the solution tube in the instrument

### Apparatus require

1. Polarimeter (See Fig. 1a)
2. Solution tube filled with the given solution (see Fig. 1b)

### Theory

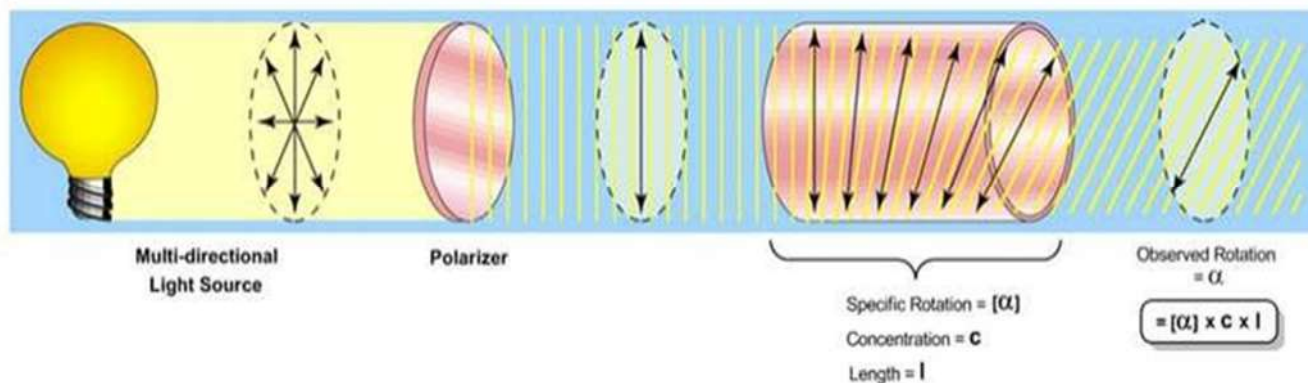


Figure 2: Specific Rotation of Plane Polarized Light from Optically Active Compound.

A polarimeter consists of two Nicols termed as polariser and analyser. These can be rotated about a common axis and the substance for which the rotation is to be determined, is placed in a tube in between these two. The half shade plate is placed between the polariser and the solution tube (cf., Fig. 3). This polarizer consists of a circular plate, one half of which is made

of quartz plate cut parallel to the optic axis. It is of such a thickness that it produces a retardation of half-a-wave-length of sodium light between the ordinary and extraordinary rays. The other half of the plate is made-up of the glass and of such a thickness that the transmitted light is of the same intensity as that coming out from the quartz. Therefore, there will be two plane polarized light beams. One will be passing out of the glass portion and other pass out of the quartz. If these two beams of the polarized light of the same intensity are inclined on the principle section of the analyser then the two halves of the field-of-view (as observed through the eyepiece) will appear equally bright.

However, in between the polarizer and analyzer, we fill the sugar solution tube which causes the rotation of the plane of the polarization of incident lights. We estimate this property of the optically active compound by measuring the specific rotation ( $[\alpha]$ ) which is a property of a chiral chemical compound. It is defined as the change in orientation of monochromatic plane-polarized light, per unit distanceconcentration product, as the light passes through a sample of a compound in the solution. Compounds which rotate light clockwise are said to be dextrorotary, and correspond with positive specific rotation. On contrary, the compounds which rotate light counterclockwise are said to be levorotary, and correspond with negative values of specific rotation. The specific rotation can be estimated as

$$\alpha = \frac{\theta}{l \times C}$$

Where  $l$  is the tube length, and  $C$  is the concentration.  $C$  is defined as the dissolve mass (gm) of the compound per unit volume (c.c).

A slight rotation in the plane of polarization in the clockwise or anticlockwise direction causes one component greater than the other. Therefore, either the quartz portion appears brighter than the glass or vice-versa. Thus, the analyzer can be set accurately so that the two halves of the field become equally bright.

## Procedure

1. Switch on the power of the polarimeter instrument.
2. Illuminate the sodium lamp (yellow light) at maximum emission. The light will pass through the solution tube.
3. Make an experiment with the distilled water. It will be filled in the tube.
4. Rotate the polarimeter using the rotating nob (see it at the bottom of the circular scale in Fig. 1 left-panel). It also rotates the circular scale.
5. First keep the eyepiece focused on the maximum intense yellow strip, and after rotation of



- the polarizer check the appearance of the intense black-strip at the same place. You will not note the corresponding scales of these two positions. This is just to examine the focus of the eyepiece for the incoming polarized light.
6. Now again keep the eyepiece focused on the position where yellow or black strip was seen with maximum contrast, and then slightly rotate the analyzer. Once the yellow or black strip disappears, i.e., fades against the background and less intense and almost uniform field-of-view appears, note the reading of circular scale as well as vernier scale.
  7. The polarizer plate consists of equal brightness of two component of polarized light at this point, so the field-of-view appears almost uniform. By slightly rotating it either in clockwise or anti-clockwise direction, the deviation from this condition will be observed (see the theory in Appendix).
  8. Fill the solution tube now with a given concentration of sugar (10 %; 5 %; 2.5 %) and perform the above experiment again and note down the corresponding readings of the circular scale.
  9. The Vernier scale has markings from 0 to 10, however, it has 20 divisions. It resembles with the 20 divisions of the circular scale (in degree). Therefore, the least count of the Vernier scale is  $0.05^\circ$ . It should be noted that the circular scale ranges from  $0^\circ$  to  $180^\circ$ .
  10. The circular scale reading is that how many its divisions already passed from the zeroth of the Vernier scale. Note that reading in the table. While, for the reading of Vernier scale we see the division of this scale which matches exactly with the division of circular scale. We multiply that division of Vernier scale with its least-count and add in the reading of the main circular scale.
  11.  $\theta_1$  is the difference between the reading of the first position on the circular scale for the sugar solution to the same for the distilled water. Similarly,  $\theta_2$  is the difference between the reading of the second position on the circular scale for the sugar solution to the same for the distilled water.
  12. Mean  $\theta$  is estimated as  $\theta_1 + \theta_2/2$ , which is the angle of the rotation of the plane of polarization of the light, when it passes through the solution.

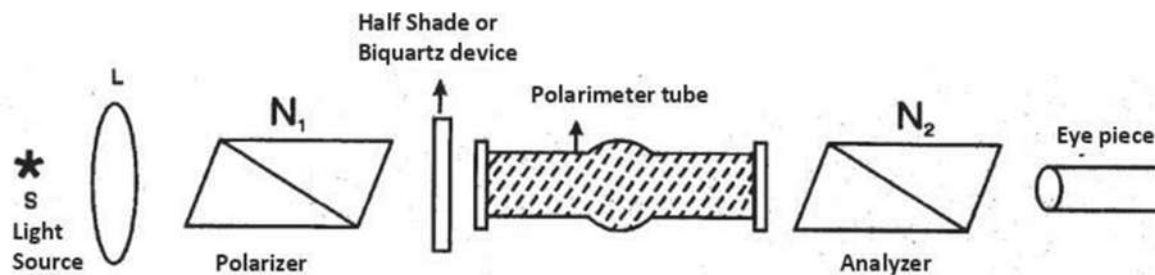


Figure 4: Schematic of the Experiment

### Tabulation:

Reading on Analyzer for Equal Illumination in Degrees												Rotation in Degrees		
With distilled water						With sugar solution						Angle ( $\theta_1$ )	Angle ( $\theta_2$ )	
First position			Second position (180° apart)			Strength of the solution per 100 c.c.	First position			Second position (180° apart)				
Main Scale	Vernier	Total	Main Scale	Vernier	Total			Main Scale	Vernier	Total	Main Scale	Vernier	Total	

### Observations

1. Room temperature = .....°C.
2. Length of the solution tube = .....dm.
3. Mass of the sugar dissolved = .....gm.
4. Volume of the solution = .....in c.c.
5. Least count of the circular scale =                   o
6. Least count of the vernier scale = ..... o =       '

### Results

1. The formula to calculate the specific rotation ( $\alpha$ ) is given by :

$$\alpha = \frac{\theta}{l} \times \frac{v}{x}$$

where  $\alpha$  = Specific rotation;  $l$  = Length of the solution tube in dm;  $V$  = Volume of the solution in c.c.;  $x$  = weight of the dissolved sugar in gm;  $\theta$  = Rotation in degrees.

2. The specific rotation ( $\alpha$ ) of the cane sugar (for a given concentration per decimeter) solution at .....°C is      °.
3. Estimate the same parameter  $\alpha$  for the different concentrations of cane sugar.
4. Error estimation as per the general instruction.
5. Draw a graph between rotation vs concentration of the solutions.

### **Precautions**

1. There should be no air-bubble in the tube while filling it with solution or distilled water.
2. While taking one set of the observations, the polarizer should not be disturbed.
3. The cap of the tube should not be tightened beyond a limit as it may strain the glass.  
Strained glass may produce elliptically polarized light which might interfere with the setting.
4. Two positions at  $\pm 90^\circ$  may appear where the equal illumination remains for a long range.  
These readings should be taken.
5. Switch off the lamp after completing the experiment.

### 3. To study the polarization of light by reflection and determine the polarizing angle for air glass interface.

**Objective-** to Study the reflection of polarized light from a glass plate

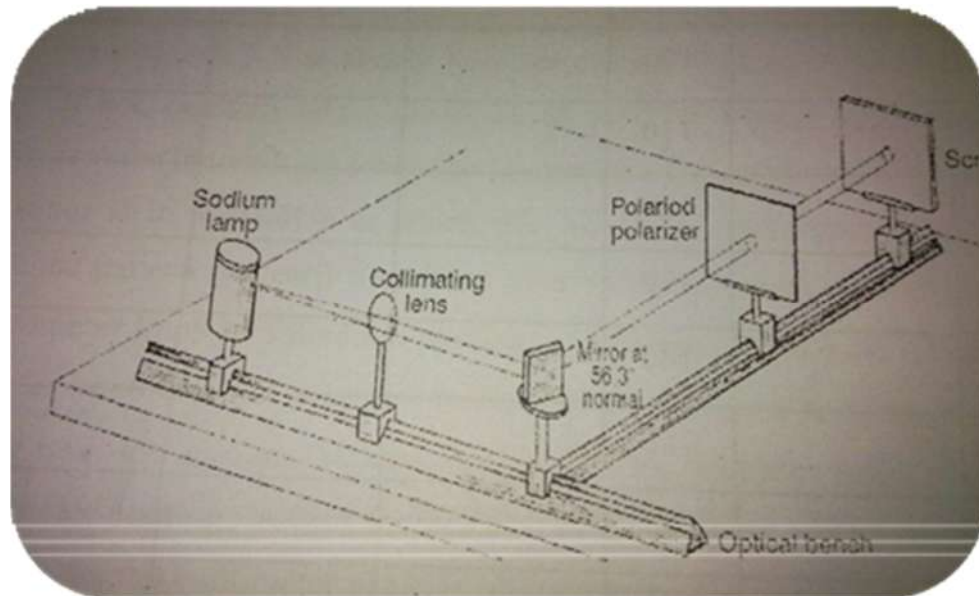


Figure1:Experimentalarrangement

#### Theory:

Probably the most familiar application of polarizing material is glare reducing sun glasses. These glasses work because the light reflected from non-conducting surfaces such as water or snow is at least partially polarized. By orienting the lens` transmission axes in the correct direction, the polarized glare can be blocked. In order to distinguish between the polarization components of reflected light, the descriptions parallel (  $\parallel$  ) and perpendicular (  $\perp$  ) are often used (rather than x and y). These terms refer to the orientation of the electric field components with respect to the plane of incidence, the plane containing the incident and reflected rays and the normal to the surface. The plane of incidence contains the incident, reflected, and refracted rays and the normal to the surface P  $\parallel$  (also called P polarization). The Fresnel equations solve for the quantity called reflectivity, which is calculated by dividing the reflected power by the incident power. That is, reflectivity is the fraction of the incident light reflected by the surface. Since there are two reflected components, perpendicular and parallel to the plane of incidence, there are two Fresnel reflection equations:

$$R_{\parallel} = \left( \frac{n_t \cos \theta_i - n_i \cos \theta_t}{n_i \cos \theta_t + n_t \cos \theta_t} \right)^2$$

$$R_{\perp} = \left( \frac{n_i \cos \theta_i - n_t \cos \theta_t}{n_i \cos \theta_i + n_t \cos \theta_t} \right)^2$$

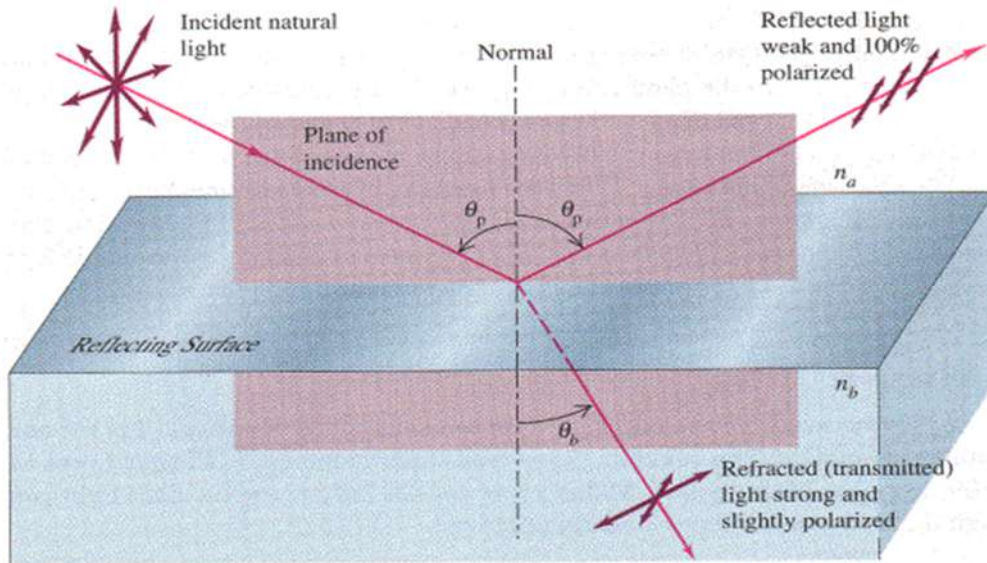


Figure 2: Polarization components for polarization by reflection

In this equation,  $n_i$  is the index of refraction of the incident material and  $n_t$  is the index of refraction of the transmitting material. The angle  $\theta_i$  is the incident angle at the material surface, and  $\theta_t$  is the refracted angle in the material, which can be found by Snell's law. It is difficult to gain an intuitive picture of the situation by looking at these equations. The graphs of Fresnel equations, Plotted in (fig 3) for the case of light incident in air ( $n_i=1$ ) and reflecting from glass ( $n_t= 1.5$ ), better explain the situation. The graphs percentage for each polarization component reflected from the surface as a function of incident angle.

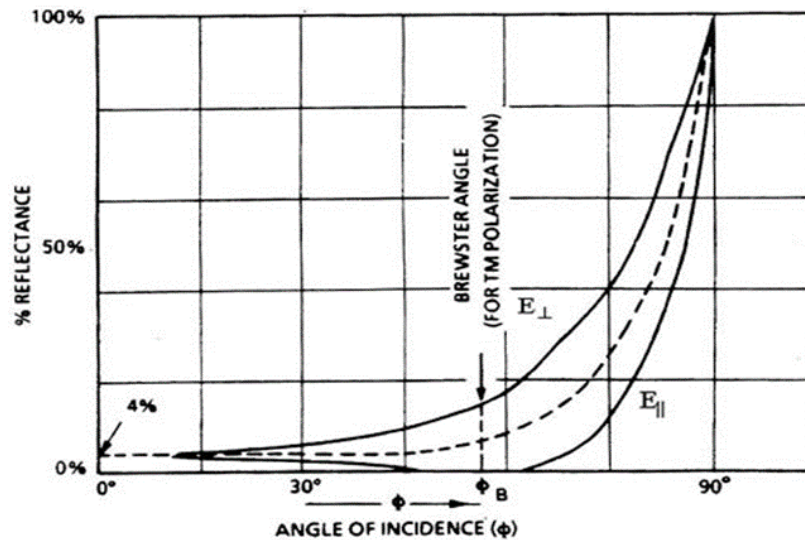


Figure 3: Fresnel reflection equation for reflection by glass in air

The graphs of reflectivity shown in fig 3 explain some everyday observations. First, note that the perpendicular component is almost always reflected more strongly than the parallel component, except the case of normal incidence where they are reflected equally. Therefore, light reflected from most surfaces tends to be at least partially polarized in the direction perpendicular to the plane of incidence. Also note that at very large angles of incidence, light of both polarizations is reflected very strongly. You may have seen this effect looking down a long tiled corridor. The Fresnel equations also predict the existence of back reflection, a source of loss in optical systems. For normal incidence ( $\theta_i=0$ ),  $\cos \theta_i = \cos \theta_t = 1$  and both of the Fresnel equations reduce to

$$R = \left( \frac{n_t - n_i}{n_t + n_i} \right)^2$$

For an air- glass interface with  $n_t= 1.5$ , the reflectivity at normal incidence is approximately 4% as shown in fig 3. Although 4% optical system with many air- glass interfaces, the total loss can be an important factor. Components may be treated with anti-reflection losses. In an optical fiber system, the reflection loss in connectors can be minimized by the use of a refractive index matching gel. Making the values of  $n_i$  and  $n_t$  nearly equal has the effect of reducing the numerator in equation and thus reducing the amount of back reflected light. The 4% reflection from an air-glass interface also explain the behavior of a window that reveals the outside world during the day time and reflect the inside world at night. Light entering from outside during daylight hours is sufficiently bright that the Fresnel reflection cannot be seen. At night, with no external light, the Fresnel reflection gives the window the appearance of a mirror.

**Equipment:**

Sodium lamp,  
collimating lens,  
Mirror at  $56.3^\circ$  normal,  
Polaroid polarizer

**Procedure:**

- 1-Change the setup to resemble fig 1.
- 2-Move the second optical bench so that light reflecting of the glass plate at  $56.3^\circ$  will go through the Polaroid and hit the screen.
- 3-By rotating the Polaroid, verify that the reflected light is polarized and determine the plane of polarization.

**Discussion:**

- 1-How would you classify sunlight?
- 2-After passing through polarizer, would you expect light to be more intense than before it passed through?
- 3-Is it possible that light, after passing through a polarizer, could remain at the same intensity? Explain.

#### 4. To verify the Stefan's law of radiation and to determine Stefan's constant.

##### Objective:

1. To verify the Stefan's law of radiation
2. To calculate the Stefan's constant.

##### Principle:

According to Stefan's law, energy radiated per unit area per unit time by a body is given as

$$P = \xi \sigma T^4$$

Where P=energy radiated per unit area per unit time i.e power

$\sigma$  = Stefan's constant

$\xi$  =emissivity of material of the body

T=temperature

For an ideal black body, emissivity  $\xi=1$ , then  $P=\sigma T^4$

##### Background

In this experiment we use a commercially available vacuum diode EZ-81 which has a cylindrical cathode made of nickel. Closely fitted inside the cathode sleeve is the tungsten heater filament. On the outer surface of the Nickel sleeve, a coating of BaO and SrO mixture is formed from which thermionic emission takes place. The cathode is heated by passing electric current through the tungsten heater filament. Temperature of the filament can be determined using known resistance (R), temperature (T) relationship for tungsten. Since the Cathode sleeve and the heater filament are in close physical contact, we can take the temperature of the cathode to be the same as that of the filament. Applying Stefan's law to the heated cylindrical cathode we can determine Stefan's constant from the knowledge of the surface area and the emissivity of the cathode which is less than unity in this case, because the radiation is not from an ideal black body. Thus according to Stefan's law:

$$P = \xi \sigma S T^n \text{ OR } \log P = \log (\xi \sigma S) + n \log T \dots\dots\dots(1)$$

$$\text{Where } P = \xi \sigma S T^n \text{ OR } \log P = \log (\xi \sigma S) + n \log T \dots\dots\dots(1)$$

$P = V I$  = Power radiated

$\xi$  = Emissivity of the cathode surface =0.24

$S = 2\pi r l$  = surface area of cathode



$r =$  Radius of the cathode  $= 0.12 \times 10^{-2}$  m

$l =$  Length of the cathode  $= 3.12 \times 10^{-2}$  m

The operating temperature of the filament can be determined from measurement of the electrical resistance of the filament and the relation is given as

$$T = 144.57 + 187.316(R_T/0.6) \dots \dots \dots (2)$$

This relation may not hold well if the filament deteriorates due to prolonged or due to oxidation of the surface of the filament. Thermionic tubes are evacuated to a high degree of vacuum and the filament placed inside the cathode sleeve of EZ-81 is covered with a thin coating of plaster of Paris for electrical insulation. Thus there is very little probability of the filament material deteriorating.

### Procedure

- 1) Put the voltmeter range switch at 1.2V position and the voltage control knob (Marked control VF) at minimum i.e. at the extreme left position.
- 2) Connect the set-up to the mains and switch 'ON'.
- 3) Apply some filament voltage VF say 0.2, 0.4, 0.6, ..... 5V to the filament and measure the corresponding filament current IF in the ammeter after steady state condition.
- 4) Determine resistance of filament as  $R_T = V_f / I_f$  and also determine the temperature T from equation (2) for each value of  $V_f$  and  $I_f$ .
- 5) Draw the graph  $\log P$  vs  $\log T$  and find the slope of the curve (value of n).
- 6) Calculate the value of  $\sigma$  from equation (1).

### Table

CONSTANT FOR DIODE EZ-81 (Vacuum tube)

Emissivity  $\xi = 0.24$

Surface area (S)  $= 2.42 \times 10^4 m^2$

S. No.	Filament Voltage $V_f$ volt	Filament Current $I_f$ A	$R_T$ Ohm	$P = V_f I_f$ watt	$R_T/0.6$ Ohm	Temperature(T) Kelvin	Log T	Log P

## **Results**

- 1) Plot of  $\log P$  vs  $\log T$
- 2) Value of Stefan's constant ( $\sigma$ )

## **Discussion**

## **Sources of Error and Error Analysis**

**Conclusion:** Write conclusions as per your results and understanding.

## 5. To determine the Boltzmann constant using V-I characteristics of PN junction diode.

**Theory:** When a positive potential is applied to the p-side of a p-n junction diode w.r.t its n side, the diode is said to be forward-biased as discussed earlier. If V is the voltage across the junction, the diode current I is given by

$$I = I_s \left[ e^{\frac{qV}{nkT}} - 1 \right]$$

Where  $I_s$  is the reverse saturation current, q is electronic charge, k is Boltzmann constant, T is the absolute temperature, and n is numerical constant depending on the material of diode.

Apparatus where n=1 for Germanium Diode

n=2 for Silicon Diode.

For silicon diode at room temperature this eqn. reduces to

$$I = I_s [\exp(19.3V) - 1]$$

Where V is the voltage across the diode in Volts.

For a positive voltage at value 0.5 – 1 V, the experimental term varies from  $1.55 \times 10^4$  to  $2.41 \times 10^8$ . Hence in this voltage range or above it, we can easily neglect '1' in this equation as compared to the exponential term and can write,

$$I = I_s \exp\left(\frac{qV}{nkT}\right)$$

$$\text{Or } \log I = \log I_s + \frac{q}{2.303} \frac{V}{nkT}$$

So a plot of  $\log I$  vs V gives  $\frac{q}{2.303 nkT}$  as the slope from which the Boltzmann constant k can be evaluated easily.

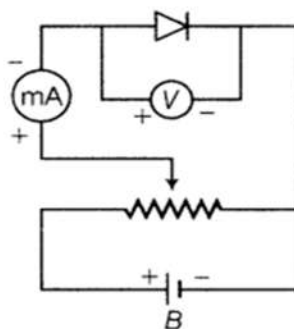


Fig: Circuit diagram

### Apparatus:

1. A p-n junction diode
2. DC power supply (5 volts)

3. A rheostat
4. A milliammeter (0-20 mA)
5. A voltmeter (0-2 volt)
6. Connecting wires

**Procedure:**

1. Make the connections as shown in the figure with p-n diode in the forward bias mode.
2. Slowly increase the input voltage from zero in convenient steps, and note the voltage V across the diode and the current I through it. Take readings till the current is about 20mA. To get a large number of readings voltmeter and milliammeter should be of low least counts. A digital multimeter can be used for the purpose.
3. Plot the graph between V along x-axis and log<sub>10</sub> i along y-axis.

**Observation and calculation:**

Temperature T= ... ° K

S.No.	Voltage, V (volts)	Current (mA)	Current I, (in Amphere)	log <sub>10</sub> I
1				
2				
3				
4				

**Calculation:**

The graph between V and log<sub>10</sub> I is a straight line is shown in the figures. Calculate the slope. [Note: The log<sub>10</sub> I are negative values, So the graph actually in the fourth quadrant but the slope remains positive.]

Boltzmann's constant k is calculated from the formula

$$k = q/2.303nT * 1/slope$$

Thus for a silicon diode at 300K

$$k = 11.59 \times 10^{-23} / slope$$

$$= ... JK^{-1}$$

## Result & Discussion

The experimentally obtained value of Boltzmann's constant = ... $\text{JK}^{-1}$

Standard value = ...  $1.38 * 10^{-23}\text{JK}^{-1}$

% Error = ...%

### Precaution:

1. Ensure that p-side is made positive w.r.t the n-side.
2. Increase the supply voltage slowly from zero. Take care that input voltage does not increase excessively; the safe value for BY 127 is about 2V. Otherwise, the diode current will be harmfully large.
3. The temperature T should be noted down in Kelvin.
4. It should be remembered that  $n=1$  for Germanium diode and 2 for Silicon diode.

**Course No: C14P:**  
**Statistical Mechanics (Lab)**  
**Credit: 2.**

<b>Sl.No</b>	<b>Experiment</b>	<b>Page No.</b>
<b>1</b>	<b>Plot Planck's law for Black Body radiation and compare it with Raleigh-Jeans Law at high temperature and low temperature</b>	<b>25</b>
<b>2</b>	<b>Plot Specific Heat of Solids (a) Dulong-Petit law, (b) Einstein distribution function, (c) Debye distribution function for high temperature and low temperature and compare them for these two cases.</b>	<b>27</b>
<b>3</b>	<b>Plot the following functions with energy at different temperatures</b> <b>a) Maxwell-Boltzmann distribution</b> <b>b) Fermi-Dirac distribution</b> <b>c) Bose-Einstein distribution</b>	<b>29</b>

# 1. Plot Planck's Law For Black Body Radiation And Compare It With Rayleigh-Jeans Law At High Temperature And Low Temperature

## Theory

The Planck's radiation law can be written in dependence of frequency or on wavelength

$$L(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1} \quad (1)$$

with,

$$U(\lambda, T) = L(\lambda, T) \frac{4\pi}{c} \quad (2)$$

Where,

L = spectral radiance (energy/unit time/unit wavelength),  $\lambda$  = wavelength, T = temperature, h = plank's constant, c = speed of light, k = boltzman constant,  $\nu$  = frequency ( $C = \lambda\nu$ ), U = spectral energy density (energy/unit time/unit wavelength)

spectral energy density for Reyleigh-Jeans law is as follows

$$U(\lambda, T) = \frac{8\pi kT}{\lambda^4} \quad (1)$$

## Program:

```
import numpy as np
from scipy.constants import h, c, k, pi
import matplotlib.pyplot as plt
L0 = np.arange(0.1,30,0.005) #Wavelength in micro m
L = L0*1e-6 #wavelength in m

def planck_lamda(L,T):
    a = (8 * pi * h * c) / L **5
    b = (h * c) / (L * k * T)
    c1 = np.exp(b) - 1
    d = a / c1
    return d

R_Ht = (8* pi *k *1100)/L**4 #Rayleigh's law at High temperature
R_Lt = (8*pi*k*200)/L**4 #Rayleigh's law at Low temperature

T200 = planck_lamda(L , 200)
T500 = planck_lamda(L , 500)
T700 = planck_lamda(L , 700)
T900 = planck_lamda(L , 900)
T1100 = planck_lamda(L , 1100)
plt.subplot(2,2,(1,2))
plt.plot(L, T200,label='T=200 K')
plt.plot(L, T500,label='T=500 K')
plt.plot(L, T700 ,label='T=700 K')
plt.plot(L, T900 ,label='T=900 K')
plt.plot(L, T1100 ,label='T=1100 K')
plt.legend(loc="best" ,prop={'size':12})
```

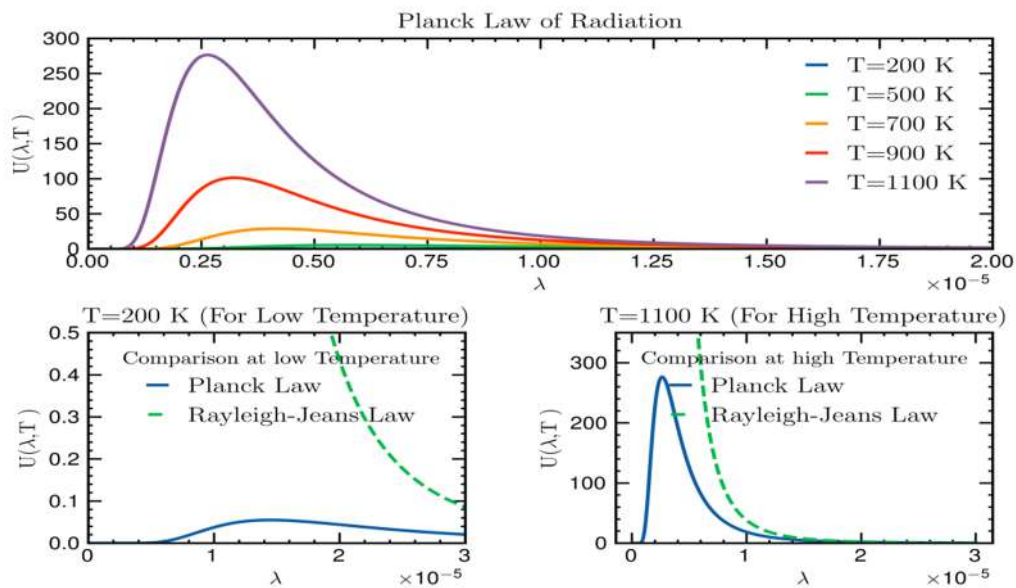


```

plt.xlabel(r"$\lambda$ ")
plt.ylabel(r"$U(\lambda, T)$")
plt.title("Planck Law of Radiation")
plt.ylim(0,300)
plt.xlim(0,0.00002)
plt.subplot(2,2,3)
plt.plot(L, (planck_lambda(L,200)),label='Planck Law')
plt.plot(L, R_Lt , "--" , label="Rayleigh-Jeans Law")
plt.legend(title="Comparison at low Temperature",loc="best" ,prop={'size':12})
plt.xlabel(r"$\lambda$ ")
plt.ylabel(r"$U(\lambda, T)$")
plt.title("T=200 K (For Low Temperature)")
plt.ylim(0,0.5)
plt.xlim(0,0.00003)
plt.subplot(2,2,4)
plt.plot(L, T1100 ,label='Planck Law')
plt.plot(L, R_Ht , "--" , label="Rayleigh-Jeans Law")
plt.legend(title="Comparison at high Temperature",loc="best" ,prop={'size':12})
plt.xlabel(r"$\lambda$ ")
plt.ylabel(r"$U(\lambda, T)$")
plt.title("T=1100 K (For High Temperature)")
plt.ylim(0,350)
plt.subplots_adjust(left=0.1, bottom=0.1, right=0.9, top=0.9, wspace=0.4, hspace=0.4)
plt.show()

```

## Result:



## 2. Plot Specific Heat Of Solids (A) Dulong-Petit Law, (B) Einstein Distribution Function, (C) Debye Distribution Function For High Temperature And Low Temperature And Compare Them For These Two Cases.

Formula used and Theory:

$$C_{vdp} = 3Nk$$

$$C_{ve} = 3Nk \left( \frac{T_e}{T} \right)^2 \frac{\exp(T_e/T)}{[\exp(T_e/T) - 1]^2}$$

$$C_{vd} = 9Nk \left( \frac{T}{T_D} \right)^3 \int_0^{\frac{T_D}{T}} \frac{y^4 e^y}{(e^y - 1)^2} dy$$

Here R = Universal Gas Constant (Joule mol / Kelvin)

h = Plank's constant

K = Boltzmann's constant

T = Temperature

$\theta_D$  = Debye Temperature

**Program:**

```
import numpy as np
from scipy.constants import h, c, k, pi
import matplotlib.pyplot as plt
from scipy.integrate import quad
r=8.314
h=6.626e-34
K=1.38e-23
thetaD=2100 #EINSTEIN temperature
v=(K*thetaD/(h))
t=np.linspace(1,3000,1000)
y=3*r #dulong-petit

def einstein(t):
    a=(h*v)/(K*t)
    E=((3*r)*(a**2)*(np.exp(a))/((np.exp(a)-1)**2));
    return E
a=(h*v)/(K*t)
```

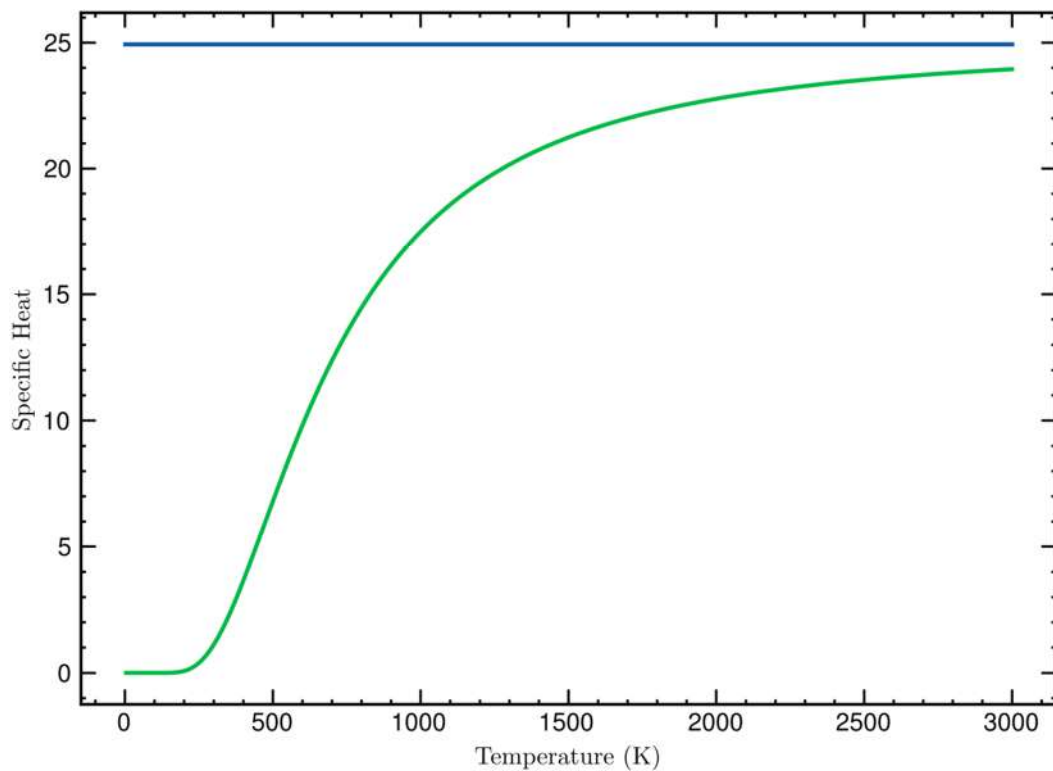
```

def ci(x):
    c=(x**4)*exp(x)/((np.exp(x)-1)**2)
    return c
integral = quad(ci, 0, a, args=())
D=(9*r*((1/a)**3)*integral);
C_v = 9 * r * (t/thetaD)**3 * np.exp(thetaD/t) / (np.exp(thetaD/t)-1)**2
l = [y]*len(t)
plt.plot(t,l)
plt.plot(t,einstein(t))

plt.xlabel('Temperature (K)')
plt.ylabel('Specific Heat')
plt.show()

```

## Output:



### 3. Plot The Following Functions With Energy at Different Temperatures

#### A) Maxwell-Boltzmann Distribution

#### B) Fermi-Dirac Distribution

#### C) Bose-Einstein Distribution

#### Theory:

1. Bose-Einstein statistics:- In case of Bose particles are indistinguishable. So the interchange of two particles between two energy states will not produce any new state.

$$n(i) = g(i) / (\exp\{\alpha + \beta\epsilon(i)\} - 1)$$

2. Fermi-Dirac statistics:- In case of Fermi-Dirac Statistics applicable to particles like electrons and obeying Pauli exclusion principle, only one particle can occupy a single energy state.

$$n(i) = g(i) / (\exp\{\alpha + \beta\epsilon(i)\} + 1)$$

3. Maxwell-Boltzmann statistics:- The conditions in Maxwell-Boltzmann statistics are-

(i) Particles are distinguishable i.e. there are no symmetry restrictions.

(ii) Each Eigen state  $i$ th quantum group may contain 0, 1, 2, 3, .....  $n$  particles.

(iii) The total number of particles in the entire system is always constant i.e.  $n = n_1 + n_2 + \dots + n_i = \sum n_i = \text{constant}$ .

(iv) The sum of energies of all the particles in different quantum groups, taken together, constitutes the total energy of the system.

$$n(i) = g(i) / \exp\{\alpha + \beta\epsilon(i)\}$$

#### Program:

```
import numpy as np
import matplotlib.pyplot as plt
E = np.linspace(-0.5,0.5,1001) #energy range
e = 1.6e-19 #electric charge
k = 1.38e-23 #Boltzmann constant(joule per kelvin)
u = 0 # considering chemical potential of the substance is zero
def Fn(T,a):
    return 1/((np.exp(((E-u)*e)/(k*T)))+a)
plt.subplot(2,2,1)
plt.plot(E,Fn(100,0),label='T = 100 K')
plt.plot(E,Fn(300,0),label='T = 300 K')
plt.plot(E,Fn(500,0),label='T = 500 K')
plt.plot(E,Fn(700,0),label='T = 700 K')
plt.ylim(0,3)
plt.xlabel('Energy(eV)')
plt.ylabel('f(E)')
plt.legend(loc='best',prop={'size':12})
plt.title("Maxwell-Boltzmann distribution for u=0")
plt.subplot(2,2,2)
plt.plot(E,Fn(100,-1),label='T = 100 K')
plt.plot(E,Fn(300,-1),label='T = 300 K')
plt.plot(E,Fn(500,-1),label='T = 500 K')
```

```

plt.plot(E,Fn(700,-1),label='T = 700 K')
plt.xlim(0,1)
plt.ylim(0,2)
plt.xlabel('Energy(eV)')
plt.ylabel('f(E)')
plt.legend(loc='best',prop={'size':12})
plt.title("Bose-Einstein distribution for u=0")
plt.subplot(2,2,3)
plt.plot(E,Fn(100,+1),label='T = 100 K')
plt.plot(E,Fn(300,+1),label='T = 300 K')
plt.plot(E,Fn(500,+1),label='T = 500 K')
plt.plot(E,Fn(700,+1),label='T = 700 K')
plt.legend(loc='best',prop={'size':12})
plt.ylim(0,1)
plt.xlabel('Energy(eV)')
plt.ylabel('f(E)')
plt.title("Fermi-Dirac distribution for u=0")
plt.subplot(2,2,4)
plt.plot(E,Fn(500,0),label='M-B distribution')
plt.plot(E,Fn(500,-1),label='B-E distribution')
plt.plot(E,Fn(500,+1),label='F-D distribution')
plt.legend(loc='best',prop={'size':12})
plt.ylim(0,4)
plt.xlabel('Energy(eV)')
plt.ylabel('f(E)')
plt.title("Temperature = 500 K")
plt.subplots_adjust(left=0.1, bottom=0.1, right=0.9, top=0.9, wspace=0.4, hspace=0.4)

```

**Output:**

