Laboratory Manual

EPHY105L, Electromagnetics

B.Tech, 1st Year, 1st Semester

Department of Physics

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Table of Contents

Experiment No. 7
Planck's constant using photoelectric effect

Aim of the experiment:
Measurement of Planck's constant using photoelectric effect and to determine work function and threshold frequency of the cathode material.

Apparatus used:
Light source with arrangement for producing light with different wavelengths and intensity, vacuum tube for photoelectric effect, voltage supply, ammeter.

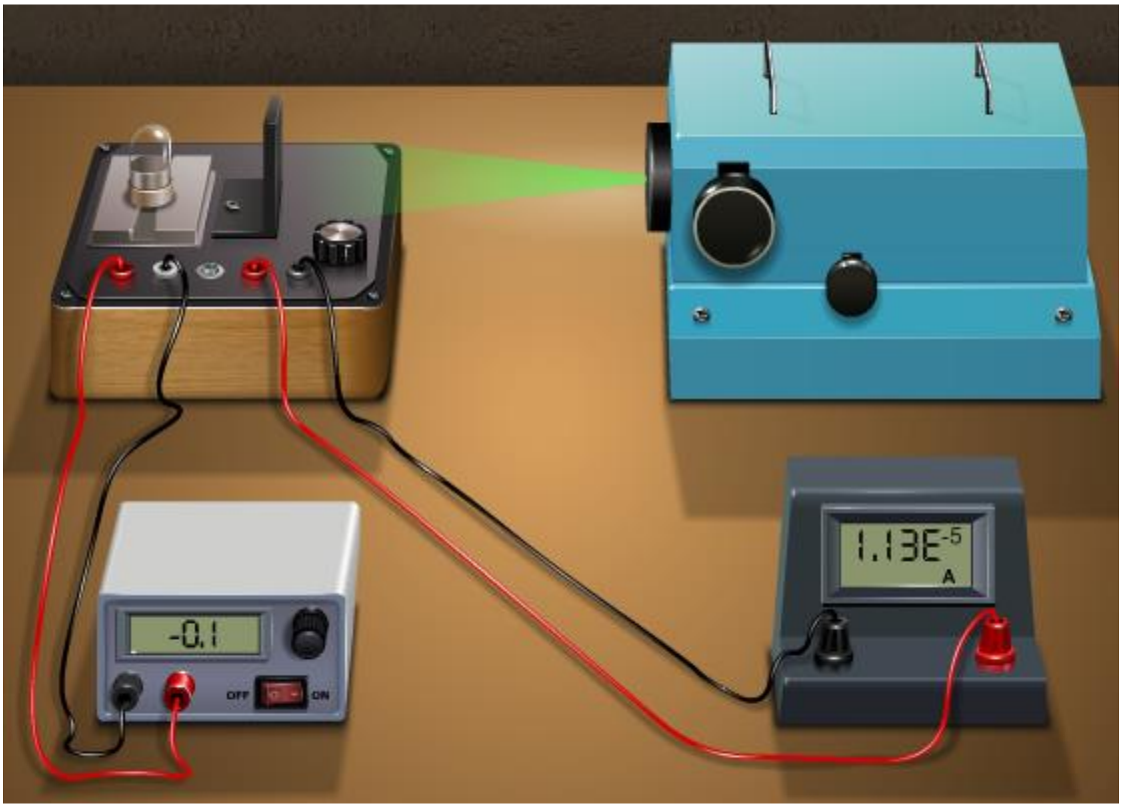


Figure 1: Experimental setup.

Theory:

The photoelectric effect is the emission of electrons when light shines on a material. Electrons emitted in this manner are also known as photo-electrons. The phenomenon was first observed by Heinrich Hertz in 1880 and explained by Albert Einstein in 1905 using Max Planck's quantum theory of light. Electrons are dislodged only by the impingement of photons when those photons exceed a certain minimum frequency (threshold frequency). Below that threshold, no electrons are emitted from the material regardless of the light intensity or the length of exposure to the light.

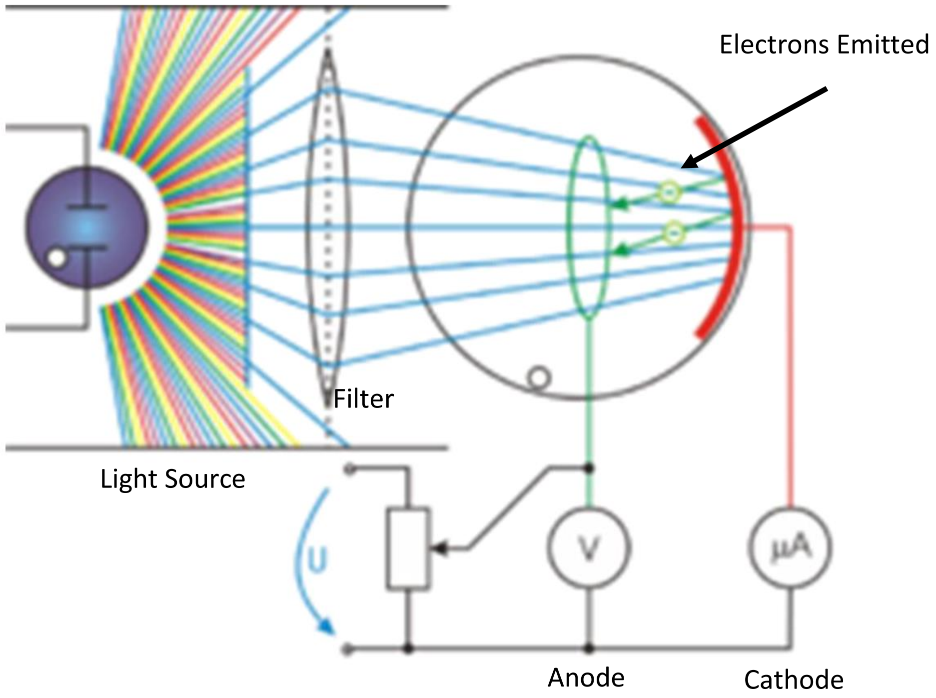


Figure2: Schematic diagram to demonstrate photoelectric effect.

According to Max Planck, radiation/light cannot have any arbitrary value of energy, instead it can only have values that are integral multiples of a certain fundamental/smallest unit, which is referred to as a quantum (plural quanta) of energy. In other words, energy of light is not continuous but discrete. In case of light this quantum of energy is also called a photon. For radiation with frequency ν or wavelength λ, the energy quantum or photon's energy is given by

$$E = h\nu = hc/\lambda \qquad (1)$$

where $c = \nu\lambda$ is the speed of light ($c = 3\text{x}10^8\ \text{ms}^{-1}$ in free space), and h is the Planck's constant. Planck's theory is one of the foundational theory of quantum mechanics. According to Einstein's theory, light has a dual wave-particle nature and each photon can be treated as a particle of light. When a photon falls on the surface of metal it collides with an electron there and its entire energy is transferred to the electron. The electrons inside a metal are bound to the metal and in order to escape they have to overcome a potential barrier, referred to as the work function of the metal. A part of the incident photon's energy is used by the electron to jump over this potential barrier and the rest stays with it as its kinetic energy. Therefore, the relation between the energy of incident photon and kinetic energy of the ejected photoelectron is

$$h\nu = \frac{1}{2}mu^2 + e\phi \tag{2}$$

where ν is the frequency of incident radiation, m is the mass of electron, e is charge of electron (1.6×10^{-19} C) , u is velocity of electron and ϕ is the work function of cathode material (in units of eV).

Photo-electrons ejected from cathode with kinetic energy $mu^2/2$ move towards the anode and constitute a photocurrent in the circuit. Now if we apply an opposing/negative voltage to the anode the electrons will be deaccelerated. On increasing the negative voltage the photocurrent gradually decreases and becomes zero at a particular value called stopping potential (suppose the magnitude of the negative stopping potential is V_S). At this point all the kinetic energy of the electrons is converted to potential energy (eV_S) due to the negative stopping potential and their velocity at the anode is 0.

$$h\nu = eV_S + e\phi \tag{3}$$

$$V_S = h\nu/\mathrm{e} - \phi \tag{4}$$

Thus, a graph between stopping voltage (V_S) and frequency of incident light (ν) would be linear with a slope (h/e). Planck's constant h can be obtained by multiplying the slope with electronic charge e. Intercept on V_S axis would give the work function ϕ in eV. Intercept on ν axis would give the threshold frequency $\left(\nu_T = \frac{e\phi}{h}\right)$ below which there is no photoelectric emission.

Procedure:

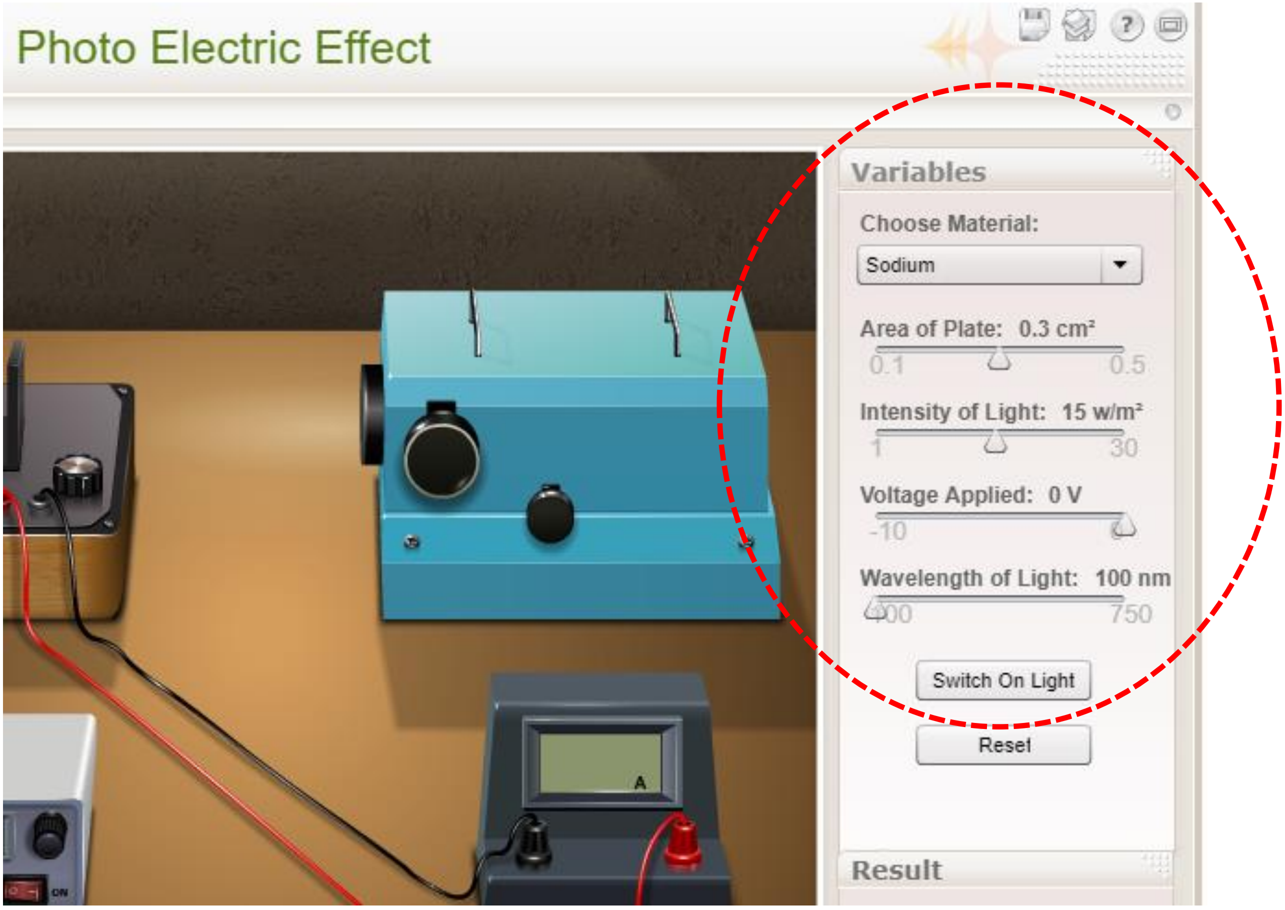
1. Go to the Amrita Vishwa Vidyapeetham virtual lab's website for Photoelectric effect experiment:

https://vlab.amrita.edu/?sub=1&brch=195&sim=840&cnt=4

2. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment. Note that the procedure mentioned below should be followed and not the procedure provided in the site.

3. Click on the "simulator" tab and login with your registered credentials to initiate the virtual experiment.

4. From the "variables" panel on the right select "sodium" from the options provided under "choose material"



5. In the "variables" panel adjust the sliders to make "area of plate" 0.3 cm^2 and "intensity of light" 15 W/m^2.

6. Click on the button "switch on light".

7. Adjust the slider "wavelength of light" and set the values provided in table I in the observations section below.

8. For each wavelength, adjust the slider "voltage applied" till the current reading in ammeter is 0. The voltage at which this happens is the stopping voltage V_S. Note down its magnitude in table I.

Observations:

Material of plate (cathode) used for photoelectric emission: Sodium
Area of the plate: 0.3 cm^2
Intensity of light: 15 W/m^2

Table I: Stopping potential versus frequency of incident light

S. No	Wavelength, λ (nm)	Frequency, $\nu = c/\lambda$ (10^{15} Hertz)	Magnitude of stopping potential, V_S (Volt)
1	150		
2	200		
3	250		
4	300		
5	350		
6	400		
7	450		

Calculations:

1. Plot the magnitude of stopping potential V_S (Y-axis) versus frequency ν (X-axis). <u>Note: Draw the X axis near the middle of your graph paper and keep both + and – Y axis</u>, because the intercept on Y axis will be in -ive Y direction.
2. Draw a best fit straight line and from the slope of the line calculate the Planck's constant, h in SI units (J.s or $Kg.m^2.s^{-1}$). Refer eqn. 4 for the calculation.
3. Find the Y-axis intercept to get the work function (ϕ in eV).
4. Find the X-axis intercept to get the threshold frequency (ν_T in 10^{15} Hz) of the cathode material.
5. Calculate the percentage errors in the obtained values of Planck's constant and work function. Use the following relation for your calculations:
   % error = $\frac{|\text{Actual value} - \text{Experimental value}|}{\text{Actual value}} \times 100$
   Actual values: $h = 6.63 \times 10^{-34}$ J.s and ϕ for sodium = 2.3 eV.

Results and Conclusions:

Planck's constant, h = ……….. Error = ………….
Work function of sodium, ϕ = ……….. Error = ………….
Threshold frequency of sodium, ν_T = ………..

Experiment No. 8
Millikan's Oil Drop Experiment

Aim: Calculation of electric charge on an oil drop and to show that electric charge exists as multiples of the charge 'e' of an electron.

Apparatus: Millikan's oil drop apparatus, oil, power supply and stopwatch.

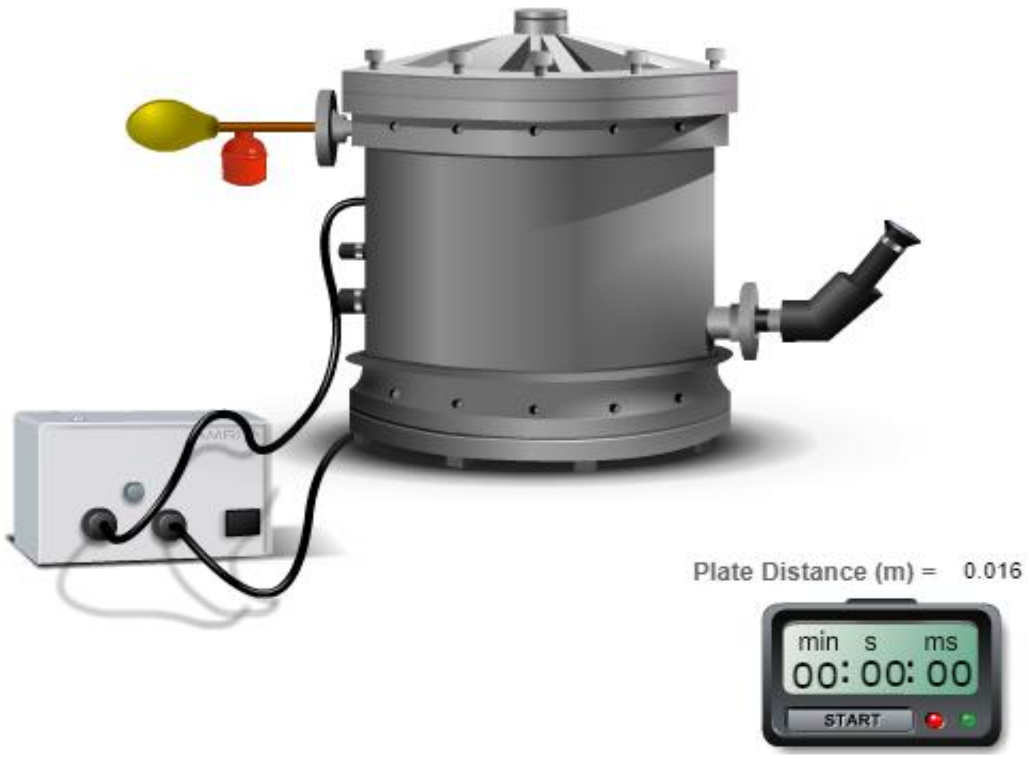


Fig. 1: Experimental setup

Theory:

This method is based on the interplay of various forces acting on an electrically charged oil drop moving in a homogeneous electric field. The forces in question are:

(i) Gravitational force, $m_{oil}g$ where m_{oil} is the mass of the oil drop and $g = 9.80665\ m/s^2$ is the acceleration due to Earth's gravitational field.

(ii) Buoyant force $m_{air}g$ where m_{air} is the mass of air displaced by the oil dop

(iii) Electric force QE where Q is the electric charge on the oil drop and E is the homogeneous electric field strength

(iv) Stokes' resistance force. Here the oil drop is considered as a sphere and the drop feels a resistance force while moving through the ambient air. Under laminar flow conditions, the viscous force (F) on a spherical object of radius r moving with a velocity v within a medium of viscosity η is given by $F = 6\pi\eta r v$.

The viscous force opposes the motion of the drop and is responsible for the steady terminal velocity the drop achieves while falling in air. We can measure the electric charge on the oil drop by measuring the falling velocity v_1 of the droplet in absence of electric field and then the rising velocity v_2 under the influence of the electric field E.

Motion of a charged oil drop in air

The forces acting on the oil drop falling through air without the influence of any electric fields are shown in Fig. 2.

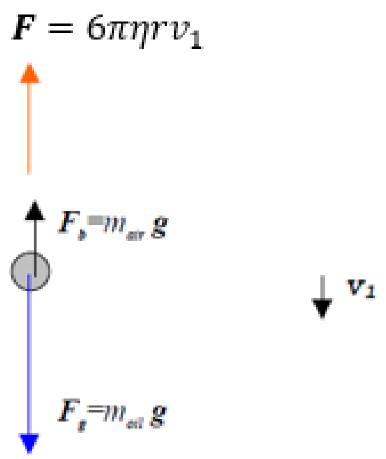


Fig. 2: Forces acting on an oil drop falling with terminal velocity $v_1$through air.

At terminal velocity of the oil drop,

$$6\pi\eta r v_1 = (m_{oil} - m_{air})g$$
$$\Rightarrow 6\pi\eta r v_1 = V(\rho_o - \rho_a)g$$
$$\Rightarrow 6\pi\eta r v_1 = \frac{4}{3}\pi r^3(\rho_o - \rho_a)g \qquad \textbf{(Eq.1)}$$
$$\Rightarrow r = \sqrt{\frac{9v_1\eta}{2g\rho}}$$

Here, $V \rightarrow$ volume of the oil drop, $\rho_o \rightarrow$ density of oil, $\rho_a \rightarrow$ density of air and $\rho = \rho_o - \rho_a$. Now let us see what happens when we switch on an electric field. Say U is the voltage between the plates in Millikan chamber and d is the distance between the plates. The resultant electric field strength $E = \frac{U}{d}$. Electric force QE and buoyant force can balance the gravitational force resulting in the droplet becoming static in the Millikan chamber

Under this condition,

$$QE = V(\rho_o - \rho_a)g$$
$$\Rightarrow QE = \frac{4}{3}\pi r^3(\rho_o - \rho_a)g \qquad \textbf{(Eq. 2)}$$

From Eq.1 and Eq.2 one can determine the charge (Q) on the drop.

$$Q\frac{U}{d} = \frac{4}{3}\pi\left(\frac{9v_1\eta}{2g\rho}\right)^{3/2}\rho g$$

$$\Rightarrow Q = v_1^{3/2}\eta^{3/2}\frac{18\pi d}{U\sqrt{2\rho g}} \qquad \textbf{(Eq. 3)}$$

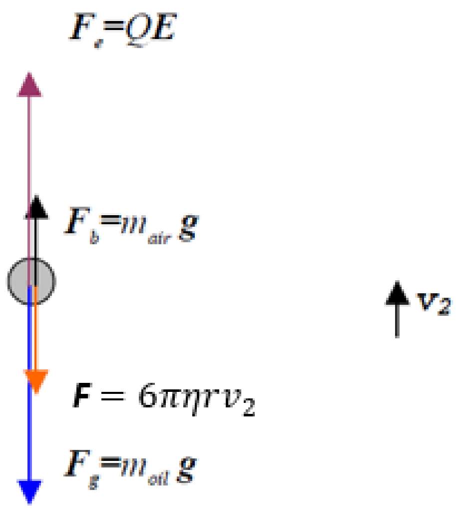


Fig. 3: Forces acting on the oil drop moving upward with terminal velocity v_2 under the influence of the electric field.

Now if we can increase the charge on the oil droplet then the electric force on it will increase and the droplet will start moving upwards. This is achieved by passing X-rays through the chamber which ionizes the air in the chamber and thus increase the charge on the droplets. Forces acting on the droplet under this condition is shown in fig. 3. The droplet soon attains a constant terminal velocity v_2 when these forces balance each other out,

$$Q'E = 6\pi\eta r v_2 + V(\rho_o - \rho_a)g$$

$$\Rightarrow Q'\frac{U}{d} = 6\pi\eta r v_2 + \frac{4}{3}\pi r^3(\rho_o - \rho_a)g \qquad \textbf{(Eq.4)}$$

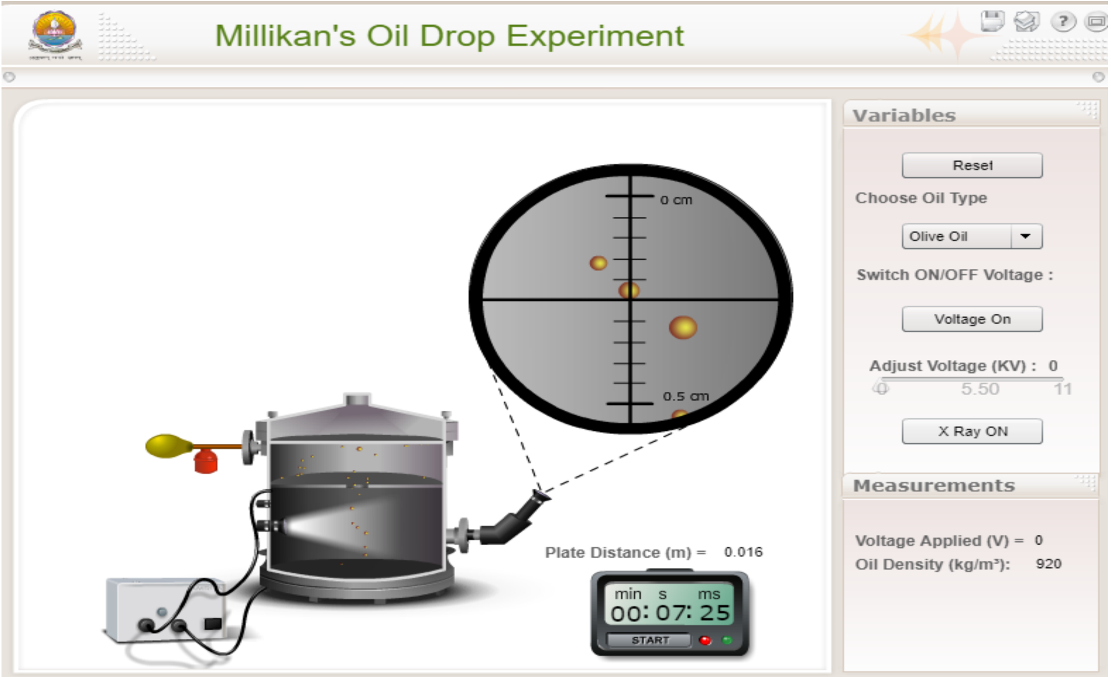
Combining Eq. 1 and Eq. 4 and solving for Q' results in

$$Q' = (v_1 + v_2)\frac{\sqrt{v_1}}{U}\eta^{3/2}\frac{18\pi d}{\sqrt{2g\rho}} \qquad \textbf{(Eq.5)}$$

Procedure:

1. Go to the Amrita Vishwa Vidyapeetham virtual lab's website for Millikan's oil drop experiment: https://vlab.amrita.edu/?sub=1&brch=195&sim=357&cnt=4
2. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment. Note that the procedure mentioned below should be followed and not the procedure provided in the site.

3. Click on the “simulator” tab and login with your registered credentials to initiate the virtual experiment.
4. Click on “start” button. Under the option “Choose oil type”, choose ‘Olive oil’.



5. Select one of the oil drops for measurement. Remember, you have to make all the measurements on one single oil drop before it goes out of the microscope view. It is therefore better to choose one of the small droplets which travel with smaller velocity.
6. Use the stopwatch to measure the time the droplet takes to travel some distance. Click on the ‘START’ button of the stopwatch to freeze the time reading. Take a mental note of the distance traveled from the scale. Make sure the oil drop does not reach too low in the microscopic field of view.
7. Immediately, click on the tab “Voltage on” and adjust the slider under “Adjust Voltage” to make the droplet stop from moving downward. Take the reading of the voltage at which the droplet remains suspended without moving in either direction.
8. Now note down the stopwatch reading and also the distance traveled by the droplet during this time. This you have to remember from the step 6 above. (If you try to note down the time and distance on step 6, you will loose time and will not be able to stop it from falling out of your field of view). From this distance and time, you can find the terminal velocity v_1
9. In the next step, click on the tab “X Ray On” to move the droplet in other direction. Be alert, since you have to use the stopwatch to note the time and distance traveled by the droplet again before it leaves the field of view. From this distance and time, you can find the terminal velocity v_2.
10. Now repeat the same steps 5-9 for 5 different droplets.

Observations and Calculations:

1. Calculate the electric charge on the oil drops using Eq.3 before the X-ray is switched on and using Eq.5, when X-ray is ON. The two charges should be different since turning on the X-ray results in more charges being added to the oil drops.
2. Find the ratios $(\frac{Q}{q})$ and $(\frac{Q'}{q})$ and round them up to the nearest integer. Calculate the percentage errors of the ratios by comparing to the nearest integer.

*Some parameters relevant for numerical calculation***:

Distance between the plates (d) : 0.016 m
Olive oil density (ρ_o) : 920 kg/m^3
Air density (ρ_a) : 1.225 kg/m^3
Electric charge on a single electron (q): $1.60217657 \times 10^{-19}$ C.
Viscosity of air (η) : 1.81×10^{-5} Pa.s or N.s/m^2
Gravitational acceleration (g) : 9.80655 m/s^2
Constant (π) : 3.14159

**Take as many decimal places as you can for all the numerical values for better accuracy.

No. of oil drop	Distance Travelled Downward, l_1 (m.)	Time taken for downward travel, t_1 (sec.)	Distance Travelled Upward, l_2 (m.)	Time taken for upward travel, t_2(sec.)	Terminal velocity (m/sec)		Balancing Potential, U (volt)	Charge of the drop, (from Eq.3) Q (C)	Charge of the drop, (from Eq.5) Q' (C)
					v_1 $(\frac{l_1}{t_1})$	v_2 $(\frac{l_2}{t_2})$			
1									
2									
3									
4									
5									

Table 1: Data for charge measurement on 5 different droplets of Olive oil

No. of oil drop	Ratio, $\frac{Q}{q}$	Nearest integer	Percentage error	Average percentage error	Ratio, $\frac{Q'}{q}$	Nearest integer	Percentage error	Average percentage error
1								
2								
3								
4								
5								

Table 2: Calculation of ratio of the charges on the oil drops to charge of an electron

Conclusions:

The electric charges on the droplets are approximately integral multiples of electric charge of a single electron.

Experiment No. 9
Anderson’s Bridge: AC Wheatstone Bridge

Aim: (a) To determine inductance (*L*) using Anderson’s bridge
(b) To determine the value of permeability of free space

Apparatus:
Resistance boxes (P, Q, R, S), Variable resistance (r), Capacitor (C), Headphone / Cathode ray oscilloscope (CRO) (H), Inductor coil (L), AC signal source (Frequency generator), Connection wires, Keys

Theory:
Anderson's bridge is a modification of Wheatstone's Bridge. This A.C bridge is often used to measure unknown value of coil's inductance using a capacitor and resistors. The circuit diagram of Anderson's bridge is given in Figure 1. In this circuit, P, Q, R, S and r are the resistances. C and L are the capacitor and inductance. The source of a.c. voltage is an audio oscillator. The bridge is balanced by adjusting the variable resistance, 'r', and it is detected by using a headphone / CRO, H instead of a moving coil galvanometer.

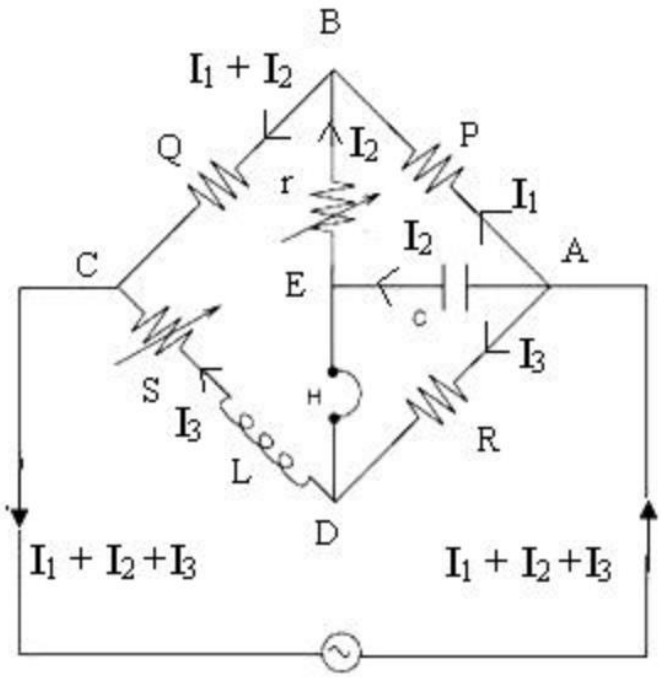


Figure 1: Circuit diagram of Anderson’s Bridge. The source of a.c. voltage is an audio oscillator and the detector is a pair of headphone H.

Balance condition:

When the bridge is balanced, we have two conditions:

(i) The potentials at points E and D are the same.

(ii) The current through the CRO (H) is zero.

Relationship between the resistances, capacitances and inductance:

To obtain a relationship between resistances (P,Q,R,S,r) , capacitance (C) and inductor (L), we will apply Kirchhoff's current law to the closed path ABCDA and ABEA.

Applying Kirchhoff's current law to the path ABCDA, we get

$$I_1 P + (I_1 + I_2)Q - I_3(S + j\omega L) - I_3 R = 0 \qquad (1)$$

where 'j' is an imaginary number, $\sqrt{-1}$. We put $j\omega L$ (and not ωL) because the phase of the e.m.f in L leads the current by 90 degree. The negative sign in Eqn. (1) indicates that direction of I_3 is opposite to I_1 and $(I_1 + I_2)$.

At the balance point, potential difference from A to E is equal to that from A to D as no current pass through the detector (H). Thus, we have

$$I_3 R = I_2 \frac{1}{j\omega C} \qquad (2)$$

Here we put $\frac{1}{j\omega C}$ (and not $\frac{1}{\omega C}$) because the e.m.f in C lags behind the current by 90 degree.

Substituting I_3 from Eqn. (2) in Eqn. (1), we get

$$I_1(P + Q) = I_2\left(\frac{R+S+j\omega L}{j\omega CR} - Q\right) \qquad (3)$$

Finally, consider the closed path ABEA and apply Kirchhoff's current law to get

$$I_1 P = I_2\left(r + \frac{1}{j\omega C}\right) \qquad (4)$$

Divide Eqn. (3) by Eqn. (4) to get

$$\frac{P+Q}{P} = \frac{R+S+j\omega(L-QCR)}{R(1+j\omega Cr)} \qquad (5)$$

After rearranging the terms in Eqn. (5), we obtain

$$RQ + j(P + Q)RC\omega = PS + j(L\omega - RC\omega Q)P \qquad (6)$$

In equation (6), we have two complex quantities on L.H.S and R.H.S, and these two complex quantities are equal if and only if their real and imaginary parts are equal to each other.

Equating the real parts of Eqn. (6) gives the following equation

$$\frac{P}{Q} = \frac{R}{S} \qquad (7)$$

which is the balance condition for Wheatstone bridge. And equating the imaginary parts of Eqn. (6), we get

$$L = C\left(Rr + \frac{Q}{P}Rr + RQ\right) \qquad (8)$$

Using Eqn. (7) in Eqn. (8), we get the following equation

$$L = C[RQ + r(R + S)] \qquad (9)$$

If we take P=Q and R=S in the circuit, then the value of the inductance is given by

$$L = CR(P + 2r) \tag{10}$$

After finding L, one can calculate the inductive reactance by using the formula

$$X_L = 2\pi f L \tag{11}$$

where 'f' is the frequency of the audio oscillator used in the circuit.

Calculation of permeability of free space:

The expression of Inductance of a solenoid is given by

$$L = \mu_0 N^2 \frac{\pi r^2}{l}$$

where

μ_0 = permeability of free space,
N = no. of turns of the coil,
l = length of solenoid,
r = radius of solenoid.

In term of the diameter of the solenoid '$d = 2r$' and number of turns per unit length '$n = N/l$' , permeability of free space is given by

$$\mu_0 = \left(\frac{4}{n^2 \pi l}\right) \frac{L}{d^2}$$

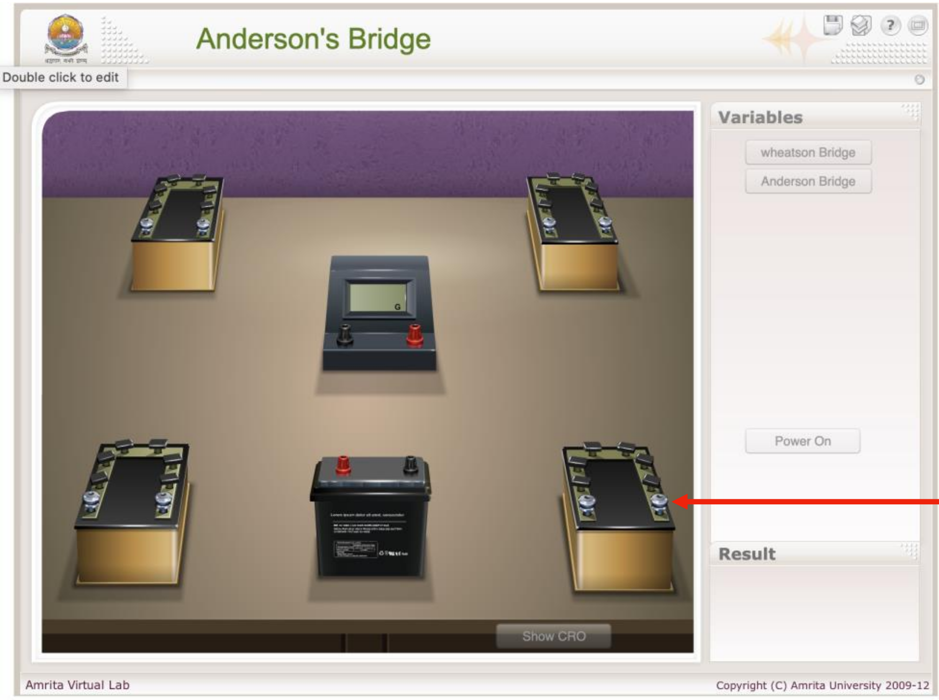
If we can find the slope of $L\ vs.\ d^2$, then the value of permeability of free space can be estimated.

Procedure:

1. Go to the Amrita Vishwa Vidyapeetham virtual lab's website for Anderson's bridge experiment. https://vlab.amrita.edu/index.php?sub=1&brch=192&sim=859&cnt=4

2. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment. Note that the procedure mentioned below should be followed and not the procedure provided in the site.

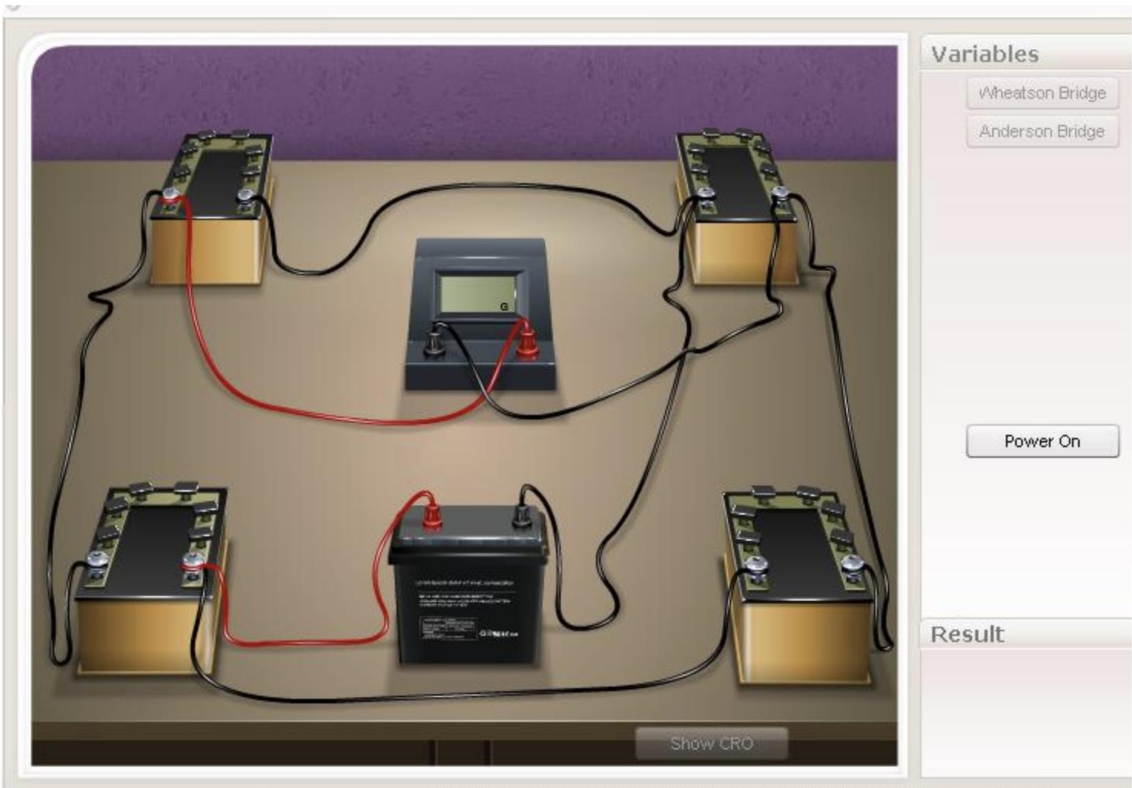
3. Click on the "simulator" tab to get apparatus for the experiment.



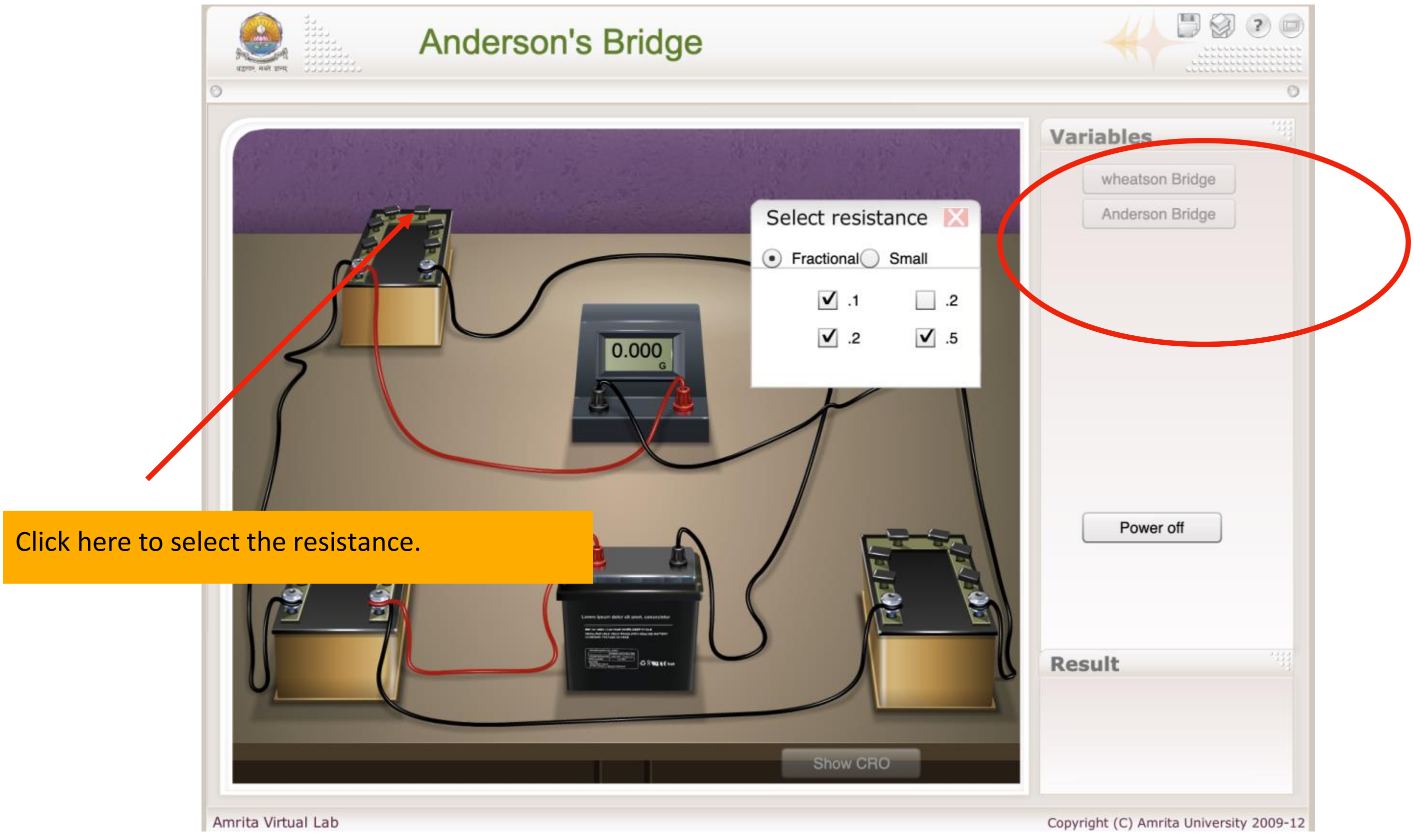
A hand sign will appear to connect wires

4. First balance D. C. Wheatstone bridge. Connect the wires to complete the circuit as follows.

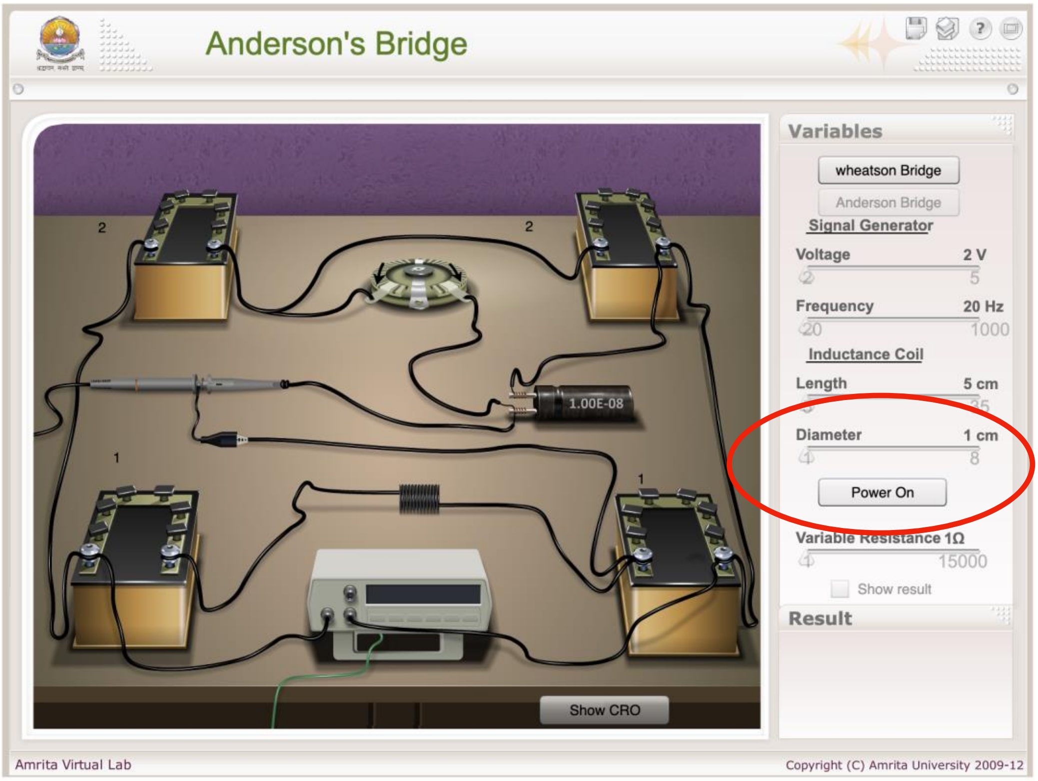
Wheatstone's bridge



5. **Switch the Power button 'On'.** Set the value of resistances P, Q, R and S using the resistance box. Take P=Q=2Ω and R=S=1Ω
6. **Anderson Bridge** will become activated only after setting the resistances.



7. Click Anderson Bridge to complete the circuit and **Click the 'Power On' button.**



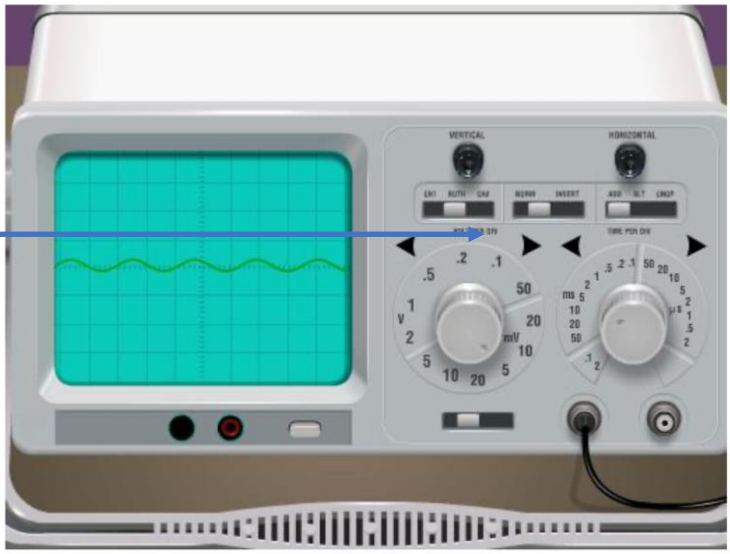
8. Adjust the sliders “Voltage” at 3 V, “Length” at 5 cm and “Frequency” at 500 Hz.

9. For each diameter ‘d’ of the solenoid given in Table I, adjust the variable resistance ‘r’ to the balance condition through CRO. In virtual lab, the balance point is detected by using a CRO, H instead of a headphone.

10. Click Show CRO. CRO is a cathode ray oscilloscope. We can visualise electrical signals by using CRO.

Use arrow sign to set:

Adjust VOL PER DIV and TIME PER DIV till you get a proper waveform.



11. Adjust ‘r’ and note the value of r, where the voltage in CRO becomes zero (you will see a straight line). It is the balancing condition.

12. Prepare Table I by changing ‘d’ and noting the value of ‘r’ for balance condition.

Observations:

Set the resistance in the Anderson’s bridge circuit as follows:
P=Q=2Ω
R=S=1Ω

Voltage = 3 V
Length =5 cm
Frequency =500 Hz
C=0.01 μF

The standard value of $\mu_0 = 4\pi \times 10^{-7} H/m$.
Expected value of L for the solenoid having diameter (d) of 2 cm is 1.97 x 10^{-5} H.

Table I: Coil-diameter (d^2) versus Inductance (L) of solenoid.

S. No	Diameter, d (cm)	d^2 (cm^2)	Variable resistor, r (Ω)	Inductance $L_{expt} = CR(P+2r)$ (H)	Impedance $X_L = 2\pi\nu L_{expt}$ (Ω)
1	2				
2	3				
3	4				
4	5				
5	6				
6	7				

Calculations:

1. Calculate error % in the value of inductance of solenoid for diameter, d = 2 cm.
   % error = $\frac{|L_{expected} - L_{experiment}|}{L_{expected}} \times 100$
2. Plot inductance (L_{expt}) vs. d^2. Find slope 'm'.
3. Find the experimental value of permeability (μ_0) using the slope of the graph (m).

   $$\frac{L}{d^2} = m = \mu_0 n^2 \frac{\pi}{4}\frac{1}{l}$$

   $$\therefore \mu_0 = \left(\frac{4}{n^2 \pi l}\right) m$$

   where,
   n = no. of turns per unit length = 10/cm,
   l = length of solenoid = 5 cm,
   d = diameter of solenoid.

4. Calculate the % error .
   $$\%error = \frac{|\mu_0 - \mu_{expt.}|}{\mu_0} \times 100$$

where, $\mu_0 = 4\pi \times 10^{-7} H/m$ is the permeability of free-space.

Results and Conclusions:

1. The experimental value of inductance L for a coil having diameter, 'd = 2 cm' is ……..
2. The % error of L for d = 2 cm is …….
3. The experimental value of permeability of free-space is …..……
4. The % error in permeability of free space is ……..

Experiment No. 10
Hall Effect

Aim:

To study Hall effect in semiconductor sample and determine the Hall coefficient and density of charge carriers. This experiment demonstrates the effect of Lorentz force.

Apparatus:

Two solenoids, constant source of power to maintain magnetic field, Hall probe with semiconductor sample, Constant current supply with ammeter and voltmeter, Gauss Meter.

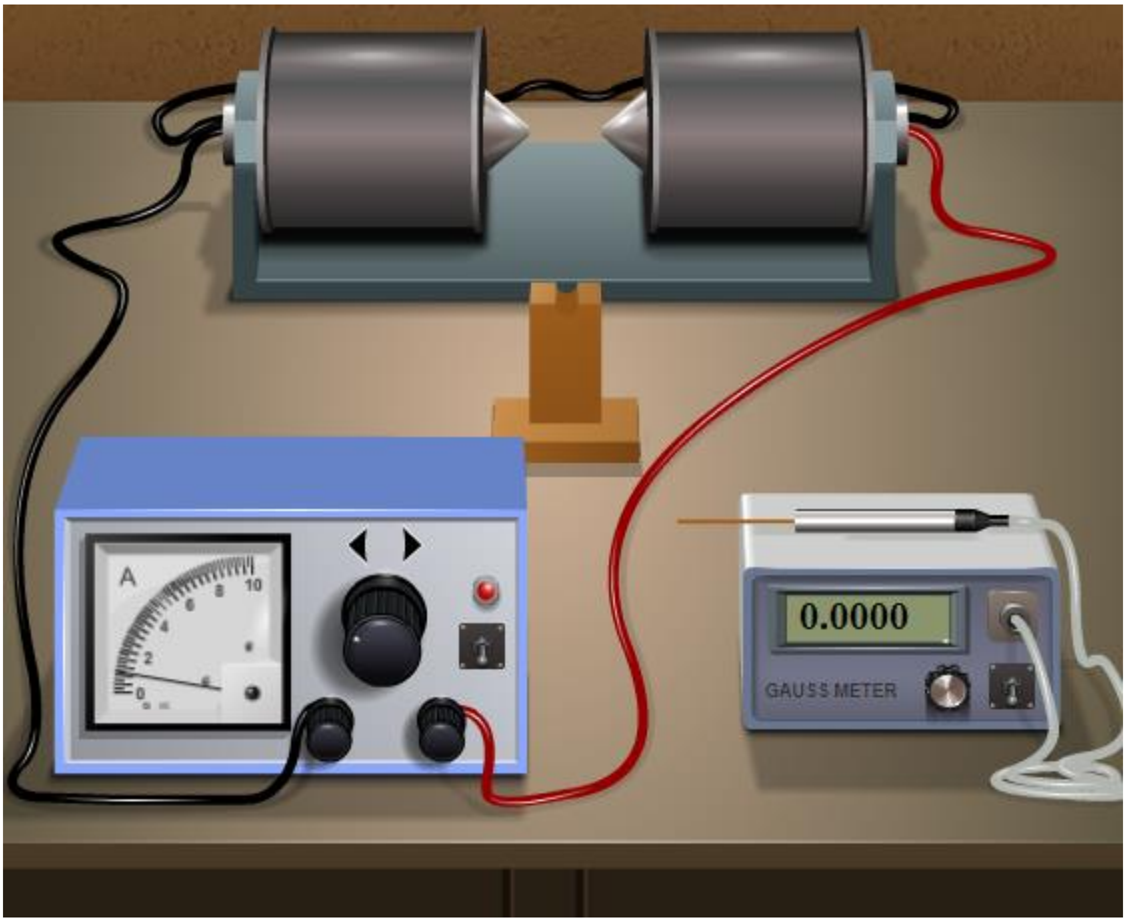


Fig. 1: Experimental setup

Theory:

Energy band structure of Semiconductors:

Atom has specific/discrete energy levels/states. When atoms are put in a periodic arrangement in a solid, the energy levels of outer shell electrons start to overlap each other. These overlapping states together is known as energy bands.

In case of semiconductor and insulator, at temperature $0K$ all the energy levels up to a certain energy band, called valence band (VB), are completely filled with electrons, while next higher energy band (called conduction band (CB)) remains completely empty. The gap between bottom of the conduction band and top of the valence band is called *fundamental energy band gap (E_g)*. It is a forbidden gap, i.e. the energy states in the gap cannot be occupied by the electrons. In case of metals, valence band is either partially occupied by electrons or valence band has an overlap with conduction band.

In case of semiconductor, the band gap $(0 - 4eV)$ is such that electrons can move from VB to CB by absorbing thermal energy. When electron moves from VB to CB it leaves behind a vacant state in VB, called hole, which can be considered as a positively charged particle (Fig. 2). When electric field is applied, movement of large number of electrons in the VB can be considered equivalent to the movement of hole in opposite direction. The E_g is a very important characteristic property of semiconductor which dictates its electrical, optical and optoelectrical properties.

There are two main types of semiconductor materials: intrinsic and extrinsic. Intrinsic semiconductor do not contain any impurity, while extrinsic semiconductor does. The process of adding impurities is called doping. Energy levels occupied by the impurity atoms are discrete and lie in the forbidden gap. The impurities are of two types: acceptor, which can accept an electron from the semiconductor and donor, which can donate an electron to the semiconductor. Extrinsic semiconductors with acceptor impurity are known as p-type semiconductors and they contain a discrete acceptor energy level just above the VB in the band gap (Fig. 2). Extrinsic semiconductors with donor impurity are known as n-type semiconductors and they contain a discrete donor energy level just below the CB in the band gap.

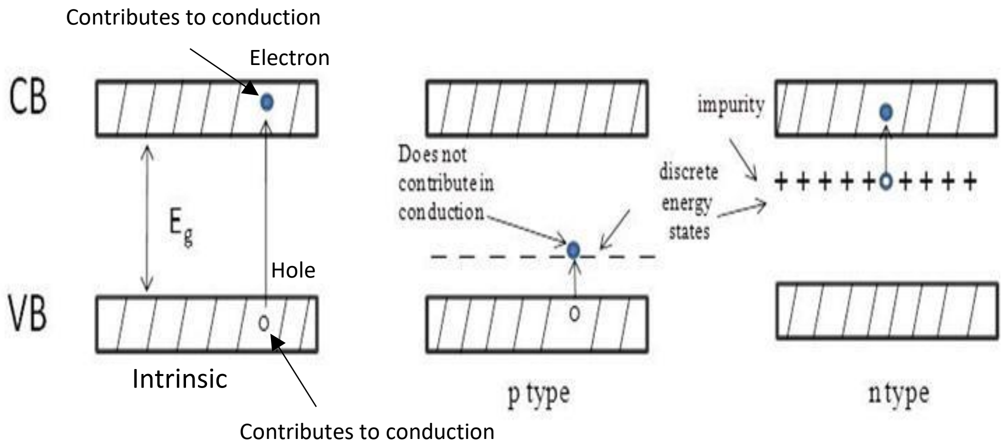


Fig. 2: Energy band diagram of a semiconductor

Hall Effect:

Consider a rectangular/cuboid slab of semiconductor [see Fig. 3], to which an electric field is applied in *x*-direction so that a current *I* flows through the sample in *x*-direction. If *w* is width of the sample (dimension along Y-direction) and *d* is the thickness (dimension along Z-direction), the current density is given by $J=I/wd$.

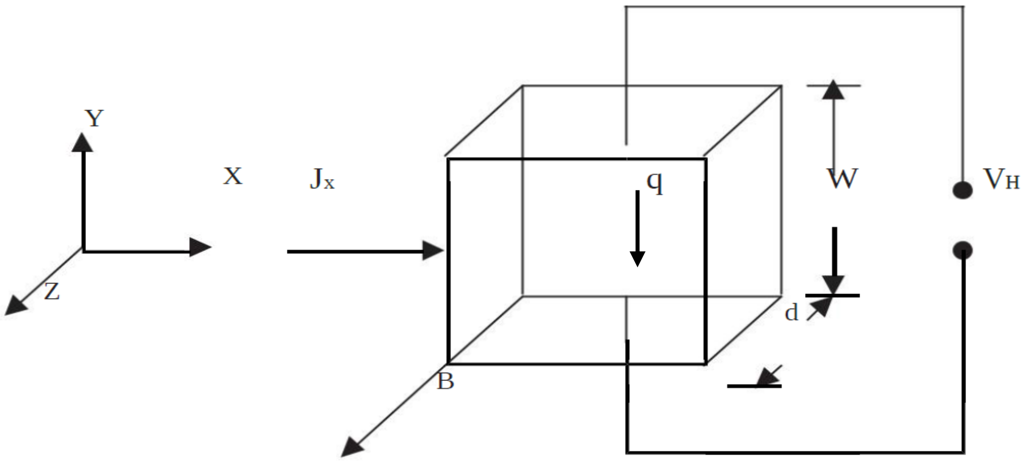


Fig. 3: Schematic representation of Hall effect measurement with a rectangular semiconductor sample.

Now a magnetic field *B* is applied along positive z axis. If the charge carriers are positive (or negative) and are moving with velocity v along positive (or negative) x-axis then the direction of Lorentz force experienced by the charge carriers in the presence of the magnetic field is along negative y direction. This results in accumulation of charge carriers towards bottom edge (fig. 3). This sets up a transverse electric field E_y in the sample that is perpendicular to both the direction of initial current and the applied magnetic field. The potential, thus developed along Y-axis is known as Hall voltage V_H and this effect is called Hall effect. Assuming E_y to be uniform the Hall voltage is given by $V_H = E_y w$ and the hall coefficient R_H is defined as:

$$R_H = \frac{E_y}{JB} = \frac{V_H d}{IB} \tag{1}$$

$$V_H = \frac{R_H B I}{d} \tag{2}$$

On varying the current *I* with a fixed *B*, the Hall voltage V_H will change linearly and the slope (*m*) is given by:

$$m = R_H B/d$$

$$R_H = md/B \tag{3}$$

The carrier density in the semiconductor (*n*) is related to the Hall coefficient by the relation

$$R_H = \frac{1}{qn}, \tag{4}$$

where *q* is the charge of the carrier ($|q| = 1.602 \text{ x } 10^{-19}$C).

From Equation (4), it is clear that the sign of the charge carrier and its density can be obtained from the *sign and value of Hall coefficient R_H.*.

Procedure:

1. Go to the Amrita Vishwa Vidyapeetham virtual lab's website for Hall Effect experiment: https://vlab.amrita.edu/?sub=1&brch=282&sim=879&cnt=4
2. Browse through the different tabs and read the material provided in the website to accustom yourself with the experiment. Note that the procedure mentioned below should be followed and not the procedure provided in the site.

3. Click on the "simulator" tab and login with your registered credentials to initiate the virtual experiment.
4. First, we have to measure the resultant magnetic field due to passing of a current through the solenoid. For this, under "Select Procedure" tab, choose "Magnetic Field Vs. Current" option.
5. Click on "Insert Probe" and subsequently on the wooden structure carrying the probe to complete the set up. It should look like the Fig. 4.

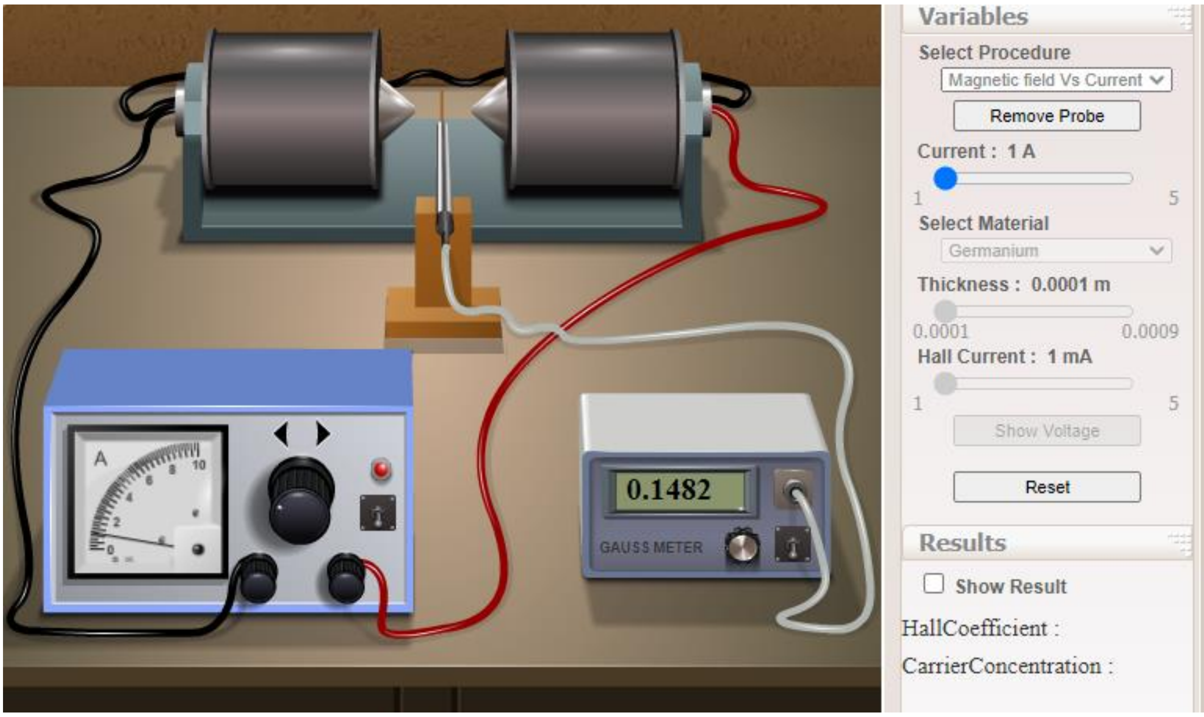


Fig. 4: Set up to measure magnetic field due to a current through the solenoid.

6. Keep the 'current' value at 1 A. Note down the resultant magnetic field from the Gaussmeter set at the lower right corner of the set up.
7. Now choose "Hall Effect Setup" under "Select Procedure" tab. Click on "Insert Hall Probe" tab and subsequently on the wooden structure within the frame to complete the setup. It should look like Fig. 5.

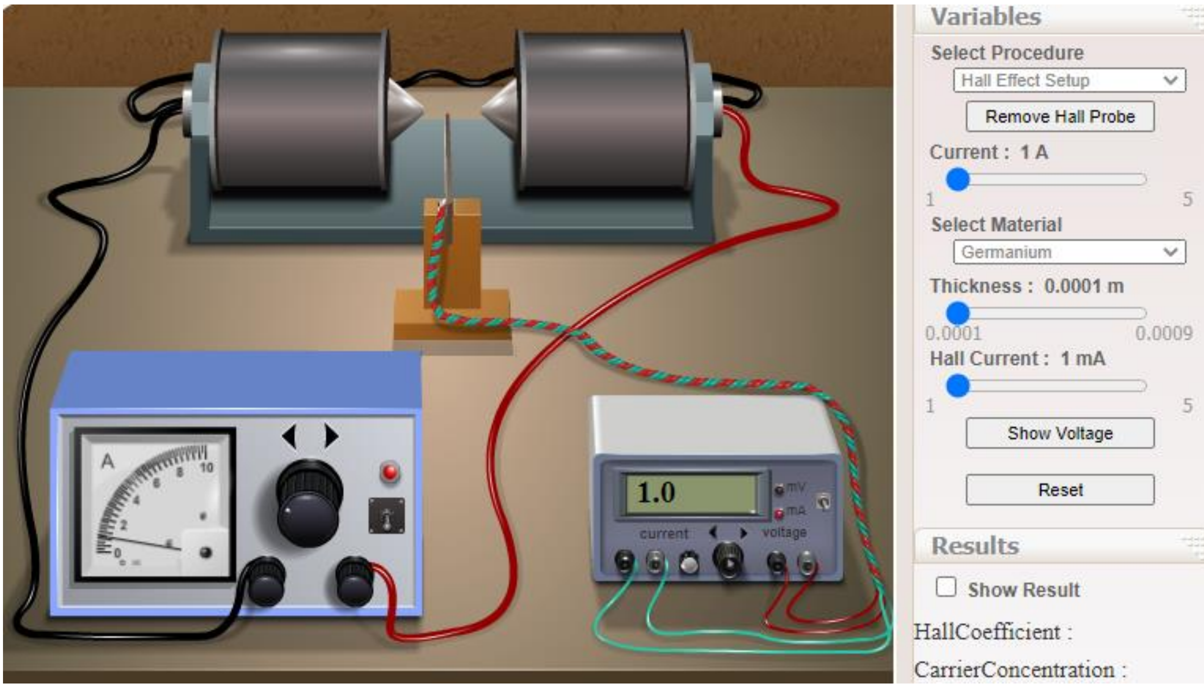


Fig. 5: Set up for the Hall effect experiment after inserting the Hall probe.

8. Keep the ‘Current’ value at 1 A and carry on with the measurements for ‘Germanium’ material under the tab “Select Material” with the default value for the “Thickness”, which is 0.0001 m.
9. Vary the “Hall Current” starting from 1 mA and note down the Hall voltage (in mV) by clicking on the “Show Voltage” tab for each current values.
10. Repeat the experiment by increasing the strength of the magnetic field by changing the current through the solenoid (keep ‘Current’ at 2.5 A) and increasing the thickness of the material (to 0.0003 m).

Observations and Calculations:

1. Plot a V_H vs. I graph from the data, with V_H on Y axis and I on X axis. Find the slope of the best fit line and calculate R_H from the slope (use Eq. 3). Be careful to convert R_H to SI units.
2. Calculate the density of charge carriers (n) in the material using Eq. 4 with the R_H data obtained from the graph.
3. Repeat with increased B and d and take the average of two R_H and n obtained from the two tables and quote the final results.

<u>Some Parameters to be used for Table 1:</u>

Current through the solenoid = 1 A

Resultant magnetic field (B) = 0.1482 G $= 0.1482 \times 10^{-4}$ T

Thickness of the material (d) = 0.0001 m

Charge of the carrier: $(|q|) = 1.602 \text{ x } 10^{-19}$ C.

Sl. No.	Hall Current, $I\ (mA)$	Hall Voltage, $V_H\ (mV)$	Hall coefficient, R_H ($\frac{\Omega m}{T}$ or $\frac{m^3}{C}$) (from slope, Eq. 3)	Density of charge carriers, n ($\frac{1}{m^3}$) (from Eq. 4)
1	1.0			
2	1.5			
3	2.0			
4	2.5			
5	3.0			
6	3.5			
7	4.0			

Table 1: Data for calculation of Hall coefficient and density of charge carriers for Germanium subjected to a fixed magnetic field.

Some Parameters to be used for Table 2:
Current through the solenoid = 2.5 A
Resultant magnetic field (B) = 0.3706 G = 0.3706×10^{-4} T
Thickness of the material (d) = 0.0003 m
Charge of the carrier: $(|q|) = 1.602$ x 10^{-19} C.

Sl. No.	Hall Current, $I\ (mA)$	Hall Voltage, $V_H\ (mV)$	Hall coefficient, R_H ($\frac{\Omega m}{T}$ or $\frac{m^3}{C}$) (from slope, Eq. 3)	Density of charge carriers, n ($\frac{1}{m^3}$) (from Eq. 4)
1	1.0			
2	1.5			
3	2.0			
4	2.5			
5	3.0			
6	3.5			
7	4.0			

Table 2: Data for calculation of Hall coefficient and density of charge carriers for Germanium subjected to a fixed magnetic field.

Results and Conclusions:

Mean $R_H = \ldots$
Mean $n = \ldots$