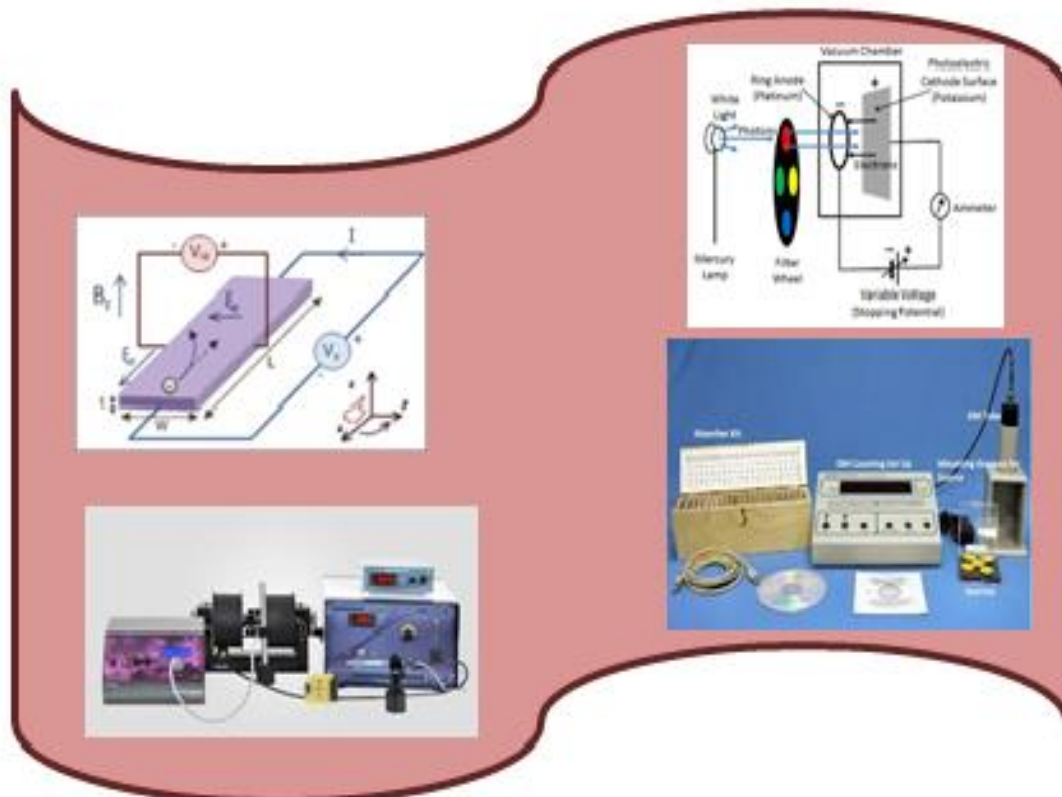




# Physics LAB-V

## Mid term Syllabus



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**Determination of planks constant by Photoelectric effect****Objectives of the experiment**

To demonstrate the photoelectric effect. To measure the kinetic energy of electrons as a function of the frequency of light. To determine Planck's constant,  $h$ . To show that the kinetic energy of electrons is independent of the intensity of light.

**Introduction**

Electrons can be liberated from the surface of certain metals by irradiating them with light of a sufficiently short wavelength, this is known as the photoelectric effect. Their energy depends on the frequency,  $\nu$ , of the incident light, but not on the intensity; the intensity only determines the number of liberated electrons. This fact contradicted the principles of classical physics, and was first interpreted in 1905 by Albert Einstein, and was one of the founding principles which gave rise to the subject of quantum mechanics. Einstein postulated that light consists of a flux of particles, called photons, whose energy  $E$  is proportional to the frequency:

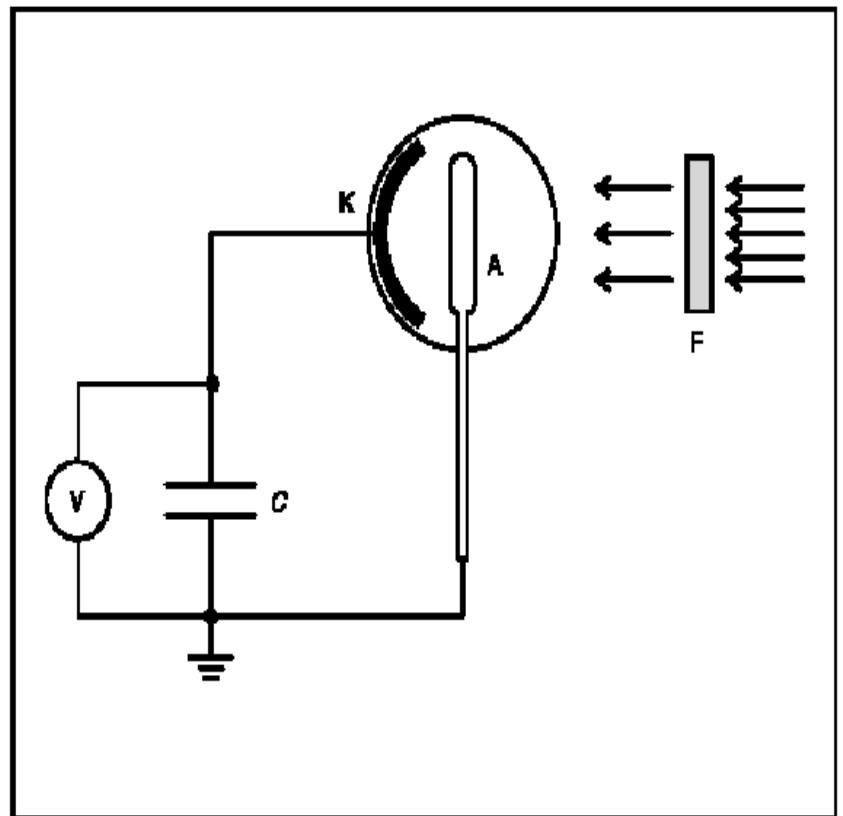
$$E = h\nu \quad (1)$$

The proportionality factor  $h$  is known as Planck's constant, and is regarded as a fundamental constant of nature. In this conception of light as being particle in nature, each photoelectron (ejected electron) exits the material with the kinetic energy

$$E_{KE} = h\nu - W_K \quad (2)$$

where  $W_K$  is the work function of the electrons, and is equal to the amount of energy required to release the electrons from the particular material. We can determine Planck's constant  $h$  by exposing a photocell to monochromatic light, i.e. light of a specific wavelength, and measuring the kinetic energy  $E_{KE}$  of the ejected electrons. Fig. 1 shows a schematic representation of such an experiment. The light falls through an annular anode, which in the present case a platinum wire, onto a potassium surface. Owing to its low work function – the valence electrons of alkali metals are weakly bound – thus potassium is a very suitable cathode material. Some of the ejected photoelectrons travel to the anode, where they are registered in the form of a photoelectric current  $I$ . If the photoelectrons are ejected against a negative

Fig. 1 Schematic representation of an experiment for measuring Planck's constant  $h$  with the aid of the photoelectric effect. Monochromatic light (produced by wavelength filter F) falls on cathode K of a photocell. The photoelectrons stimulated here travel to anode A and charge capacitor C up to the limit voltage  $U_0$ .



potential which is gradually increased, the photoelectric current continually decreases. The voltage at which the photoelectric current reaches precisely zero is called the limit voltage  $U_0$ . At this level, even the electrons with the weakest bonds, i.e. those with the lowest work function  $W_K$  and thus the greatest kinetic energy, can no longer overcome the anode voltage. In this experiment, the anode voltage is generated using a capacitor which is charged by the incident electrons up to a limit voltage  $U_0$  (see Fig. 1). We can use this limit voltage  $U_0$  to calculate the kinetic energy of these weakly bound electrons:

$$eU_0 = h\nu - W \quad (3)$$

where  $e$  is the elementary electron charge.

Note, here,  $W$  is no longer the work function  $W_K$  of the cathode, as the contact potential between the cathode and the anode is included in the energy balance.

The measurements are conducted for various wavelengths  $\lambda$  and frequencies

$$\nu = \frac{c}{\lambda} \quad (4)$$

where  $c$  is the speed of light in a vacuum. When the frequency of the incident light increases by  $\Delta\nu$ , the electron energy increases by  $h\Delta\nu$ . The limit voltage must be increased by  $\Delta U_0$  to compensate for the rise in the photoelectric current. When we plot the limit voltage  $U_0(\nu)$  as a function of  $\nu$ , equation (3) gives a straight line with the slope:

$$\frac{\Delta U_0}{\Delta \nu} = \frac{h}{e} \quad (5)$$

For a known elementary charge  $e$ , this gives Planck's constant  $h$ . In this experiment, narrow-band interference filters are used to select the wavelengths; each filter selects precisely one spectral line from the light of a high-pressure mercury lamp. The wavelength specification on the filter refers to the wavelength of the transmitted mercury line.

## Experimental Details

The experiment involves the use of a high pressure mercury lamp. **Note that the lamp also emits light in the UV band and this can cause damage to the eyes. So never look directly at the lamp, nor at reflections.** The lamp itself does not reach full intensity until after 10 minutes. Switch on the lamp whilst you are setting up the experiment so that it reaches full intensity when you are ready to make measurements. Fig 2. shows the experimental set-up.

- Connect the mercury lamp power supply to the mains via the distribution box.
- Mount the high-pressure mercury lamp at the marked position using an optical rider (height,  $H = 90$  mm), connect it to the power supply and switch it on.
- Mount the photocell at the marked position using an optical rider ( $H = 90$  mm); remove the cover and align the photocell so that the coated black surface is facing the mercury lamp.
- Mount the iris diaphragm on the optical bench at the marked position using an optical rider ( $H = 120$  mm).
- Mount the lens at the marked position using an optical rider ( $H = 120$  mm) and adjust

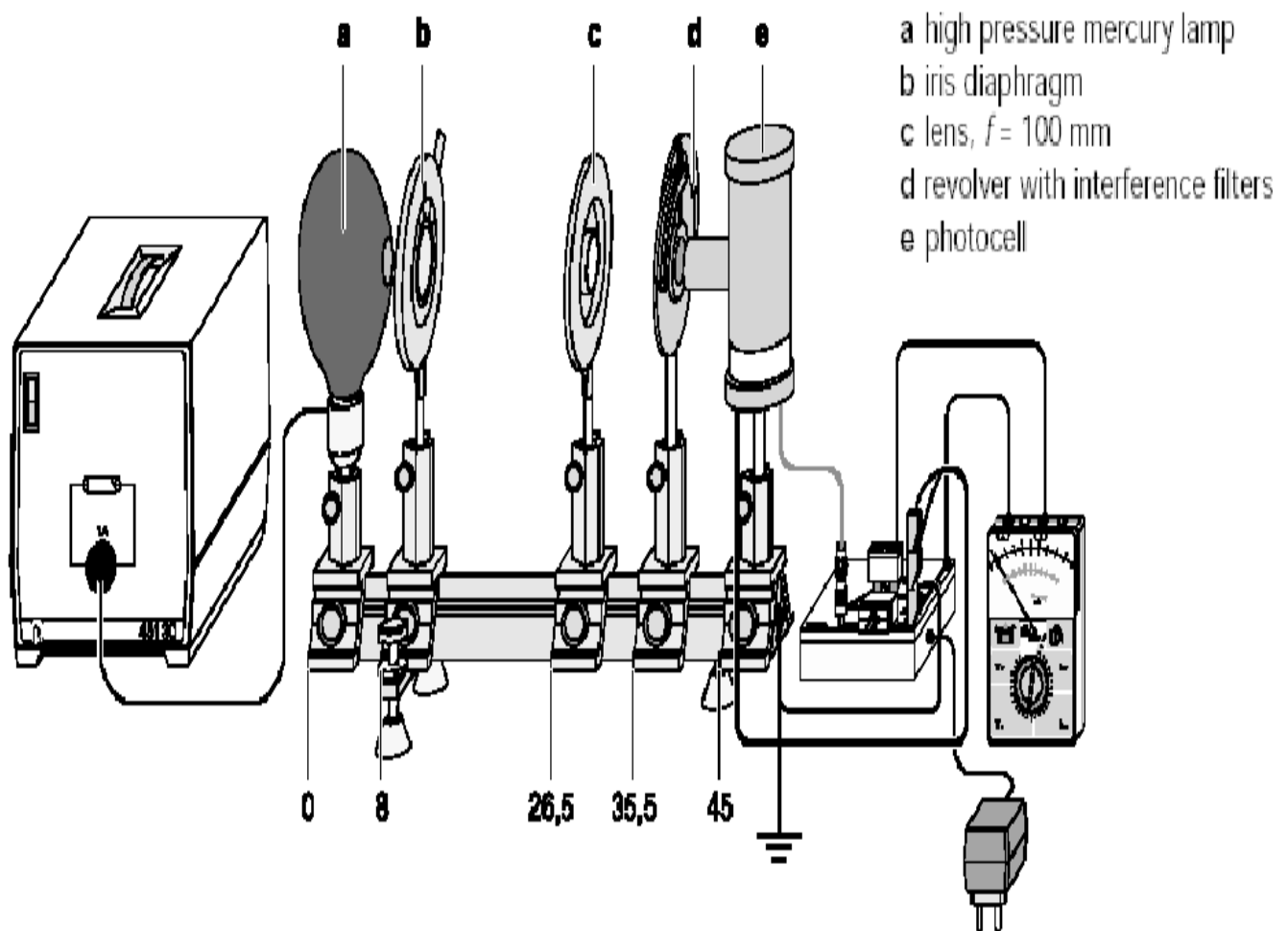


Fig. 2. The experimental arrangements of the various pieces of equipment. The distances between each element is given in cm in the lower part of the figure.

its height so that the center of the lens is at the same height as the center of the iris diaphragm. The light from the mercury lamp should now produce a sharp light spot on the black coating (the sensitive area) of the photocell. The light should not fall on the metal ring nor on the part of the black-coated area to which the contacts are attached.

The edge zones should not be illuminated either. To ensure that this is so, carry out the following procedure, repeating as often as necessary to produce the optimum image:

- Vary the height of the iris diaphragm and the lens so that the light spot falls on the black zone of the photocell; make sure that the center of the lens is always on the same level with that of the iris diaphragm. You may also need to adjust the height and inclination of the photocell (using the screws below the base).
- Using the iris diaphragm, adjust the size of the light spot so that it illuminates the largest possible area of the black zone of the photocell, without shining on the outer zones, the metal ring or the contacts on the black coating.
- Focus the light spot as necessary by moving the lens along the optical bench.
- Place the cover on the photocell.
- Place the filter revolver with iris diaphragm directly in front of the photocell using an optical rider ( $H = 120 \text{ mm}$ ) and connect the iris diaphragm of the filter revolver with the cover of the photocell to prevent scattered light from reaching the photocell.

**Electrical assembly:**

The photoelectrons incident on the metal ring of the photocell charge a capacitor, generating the limit voltage  $U_0$  required for determining the kinetic energy. The electrometer amplifier is used to measure the voltage at the capacitor.

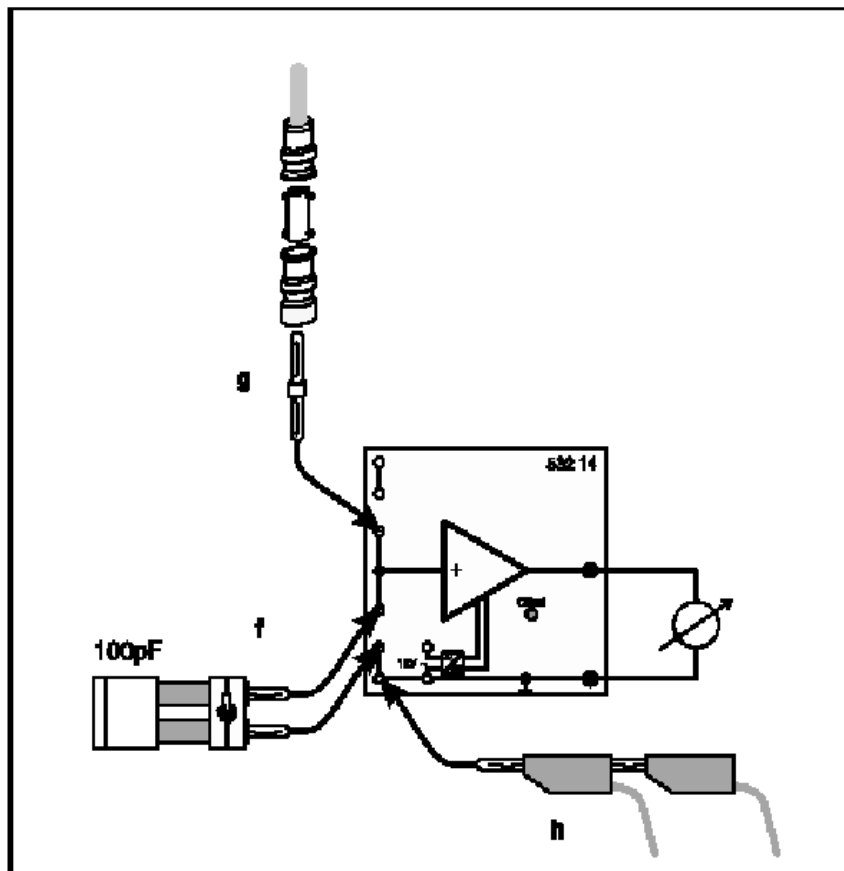
Set up the electrometer amplifier circuit as shown in Fig. 3.

- Attach terminal plug (f) and connect the 100 pF capacitor and the key switch.
- Attach coupling plug (g), the BNC/4 mm adapter and the straight BNC and connect these to the gray screened cable of the photocell.
- Connect both black cables (h) of the photocell to the ground connection on the electrometer amplifier.
- Connect the multimeter to the output of the electrometer amplifier.

Also:

- Connect the plug-in supply unit (12 V) to the electrometer amplifier and plug it in via the distribution box.
- Connect the optical bench (and possibly the rod of the basic device of the photocell) to the ground connection of the electrometer amplifier, and connect this terminal to the external ground of the distribution box or power supply.

Fig. 3 Electrometer amplifier circuit for measuring the limit voltage  $U_0$





### Carrying out the experiment

#### *Notes:*

*Dirt on the photocell can cause leakage currents between the anode and the cathode which can affect the measurement of the limit voltage  $U_0$ . Clean the photocell with alcohol. The voltage at the capacitor can be influenced by induction effects. Move this part as little as possible during the experiment. You do not need to darken the room; this has no effect on the measurement results.*

- Switch on the multimeter and set the range switch to V DC.
- Turn the interference filter for yellow light ( $\lambda_{\text{Hg}} = 578 \text{ nm}$ ) into the beam path.
- Discharge the capacitor by holding down the key switch until the multimeter reads zero V.
- Start the measurement by releasing the key switch; wait about 30 s to 1 minute, until the capacitor has charged to the limit voltage  $U_0$ . Write down the measured value for  $U_0$ .
- Turn the interference filter for green light ( $\lambda_{\text{Hg}} = 546 \text{ nm}$ ) into the beam path and repeat the measurement.
- Repeat the measurement with the blue ( $\lambda_{\text{Hg}} = 436 \text{ nm}$ ) and violet ( $\lambda_{\text{Hg}} = 405 \text{ nm}$ ) interference filters.
- Vary the intensity of the incident light at the photocell using the iris diaphragm of the filter revolver and measure the limit voltage  $U_0$  for each setting.

*Note: If the iris diaphragm is closed too far, this may affect the uniform illumination of the light spot on the cathode. Also, leakage currents will play an increasing role.*

Deduce a value of Planck's constant from your measurements.

# Geiger-Mueller Counting

## Introduction:

### 3.1. Radioactivity:

*“Radioactivity defined as the spontaneous emission of particles or rays or both at the same time, from the decay of certain nuclides that these particles are, due to an adjustment of their internal structure.”*

In nature there are some elements which are unstable. Unstable mean they possess some extra amount of energy in the nucleus. This energy makes them unstable. These elements emit energy by some process. This phenomenon is called radioactivity. Radioactivity was discovered by Becquerel in 1896 when he wrapped a photographic plate around uranium sample. The radiation emitted from uranium was later recognized as alpha particles. Later on, other type of radiations was also discovered known as beta particles and gamma particles. Unstable elements get rid of extra energy by some processes and they decay into some other element. This process is called radioactive decay and elements are called radioactive elements.

### 3.2. Types of Radioactive Decay:

There are three basic processes by which unstable elements decay to some other elements which may be stable.

#### 3.2.1. *Alpha decay:*

Emission of alpha particles from a heavy unstable nucleus is called alpha decay. Alpha particles have two protons and two neutrons, so in this process atomic number of parent nucleus is changed by 2 and mass number is changed by 4. Some energy is also emitted in this process. Uranium, plutonium etc. are alpha particle emitters.

#### 3.2.2. *Beta decay:*

Elements which emit beta particles from their nucleus are called beta emitters and process is called beta decay. In this process either a positive electron (positron) is emitted or a negative electron is emitted. In positron emission a proton is converted into neutron and positron is emitted. This process will convert atom to next below atomic number element. In electron

emission process a neutron is converted into proton and an electron is produced. An electron has energy very less so it cannot stay inside nucleus so they are emitted and so atom is transformed into next above atomic number element. There is another process which takes place in beta decay that is called electron capture. In this process an electron from electronic shell is swallowed by nucleus and a proton is converted into neutron so atom is transmuted into next below atomic number element.

### 3.2.3. *Gamma decay:*

Atoms emitting gamma radiation is called gamma emitters and phenomena is called gamma decay. During some nuclear reactions or in some decay processes discussed above, atom after reaction may have some excess amount which it can emit through nuclear transitions, called gamma radiations. In gamma decay no nuclear transmutation takes place but atoms are only transformed from excited to ground states.

### 3.3.Geiger Muller Counter:

Geiger-Muller (GM) counters were invented by H. Geiger and E.W. Müller in 1928, and are used to detect radioactive particles. Alpha, Gamma and Beta radiations are invisible to humans and exposure to these radiations can be hazardous to the health of living organisms. It is therefore extremely important that suitably designed detectors are available in order to gain information on the type and amount of radiation present.

#### 3.3.1. *Construction & Working:*

It consists of a metallic chamber with a thin central tungsten wire insulated from the outer chamber. The central wire is at positive with respect to the outer chamber and hence the central wire acts as anode while the outer serves as cathode. If the outer chamber is made out of glass, then its inner surface is wanted with some conducting material to serve as cathode. **Geiger-Muller Counter** is usually filled with noble gases such as argon, neon etc.

When ionizing radiation such as an alpha, beta or gamma particle enters the tube, it can ionize some of the gas molecules in the tube. From these ionized atoms, an electron is knocked out of the atom, and the remaining atom is positively charged. The high voltage in the tube produces an electric field inside the tube. The electrons that were knocked out of the atom are attracted to the positive electrode, and the positively charged ions are attracted to the negative electrode. This produces a pulse of current in the wires connecting the electrodes, and this pulse is counted.

After the pulse is counted, the charged ions become neutralized, and the Geiger counter is ready to record another pulse. In order for the Geiger counter tube to restore itself quickly to its original state after radiation has entered, a gas is added to the tube. For proper use of the Geiger counter, one must have the appropriate voltage across the electrodes. If the voltage is too low, the electric field in the tube is too weak to cause a current pulse. If the voltage is too high, the tube will undergo continuous discharge, and the tube can be damaged. Usually the manufacture recommends the correct voltage to use for the tube. Larger tubes require larger voltages to produce the necessary electric fields inside the tube.

#### 3.3.2. Characteristics of GM tubes:-

The important parameters which decide the quality of functioning of Gm tubes are  
Dead time  
Recovery time  
Plateau length & Plateau slope

#### ***3.3.2.1. Quenching of GM tube:***

As ions and electrons are generated in gas present inside the GM tube. These ions and electrons move to opposite sides and reach the cathode and anode completing circuit and producing current pulse. These ions and electrons, under the action of high voltage, can get a large kinetic energy and when they strike the cathode or anode (for electron) they producing a sputtering effect. In effect it can eject electrons from cathode and these electrons and produces its own current. This process produces an unwanted current and in GM tube which make busy the counter and so next pulse is not recorded. To remove this process, heavy molecular mass molecules multi atom gas is added to GM tube. This gas is called quenching gas. This gas decrease the kinetic energy of ions striking the cathode and therefore sputtering process is avoided and this process is called quenching.

#### ***3.3.2.2. Dead time:***

As, the positive ions take considerable time to reach cathode tube compared to electrons. The reason is that the mobility of electrons is about 1000 times greater than that of electrons. Due to the low drift velocity of positive ions, there is formation of cloud of positive ions which tend to electric field opposite to that of actual field. This reduces the electric field intensity due to anode potential and thus affects gas multiplication factor. This in turn affects the pulse heights.

In high count rates, it is more worse that there is formation of dense positive cloud which makes the electric field intensity in the vicinity of anode wire reduce by great margin thus multiplication goes down by big margin. During this phase of detector, any new ionizing event caused by incoming particle cannot be recorded. Thus the time interval during which any event caused by newly incoming particle would not get counted and called as dead time of the country.

#### ***3.3.2.3. Recovery time:***

After certain time, all the positive ions tend to reach cathode wall and thus the electric field begins to restore to actual value. When the electric field goes beyond a critical value there is again formation for pulses. But the process requires some time to give maximum pulse heights. Hence the total time required for GM tube to give maximum pulse height pulses is Recovery time.

#### ***3.3.2.4. Plateau length & Slope:***

In order to decide the operating voltage of the GM tube, a graph between anode voltage (X axis) and count rate (Y axis) is plotted. After applying minimum voltage to initiate Geiger discharge, the no. of pulses shall remain same in fixed radiation field exposure. But due to formation of short pulses during recovery time there is variation in count rate. Thus one of the quality parameters deciding the operation of GM tube is that plateau slope shall be less. Usually 2-3%

plateau slope is a good choice. As we go on applying voltage to the anode, the tube starts entering continuous discharge region. Thus the slope gets worsened. The region or length of voltage region during which the plateau slope remains in desired value is called as plateau length and usually the operating voltage is chosen at the midpoint of plateau length.

### 3.3.3. Limitation:

There are two main limitations of the Geiger counter. Because the output pulse from a Geiger-Muller tube is always the same magnitude regardless of the energy of the incident radiation, the tube cannot differentiate between radiation types. A further limitation is the inability to measure high radiation rates due to the "dead time" of the tube. This is an insensitive period after each ionization of the gas during which any further incident radiation will not result in a count.



Week 5



## Experiment # 2

### Operating Plateau for the Geiger Tube

#### Purpose

The purpose of this experiment is to determine the voltage plateau for the Geiger tube and to establish a reasonable operating point for the tube. Fig. 2.2 shows a counts-vs.-voltage curve for a typical Geiger tube that has an operating point in the vicinity of 950 V.

The region between R1 and R2, corresponding to operating voltages V1 and V2, is called the Geiger region. Voltages  $>V2$  in Fig. 2.2 cause a continuous discharge in the tube and should be avoided, because a continuous discharge will definitely shorten the life of the tube.

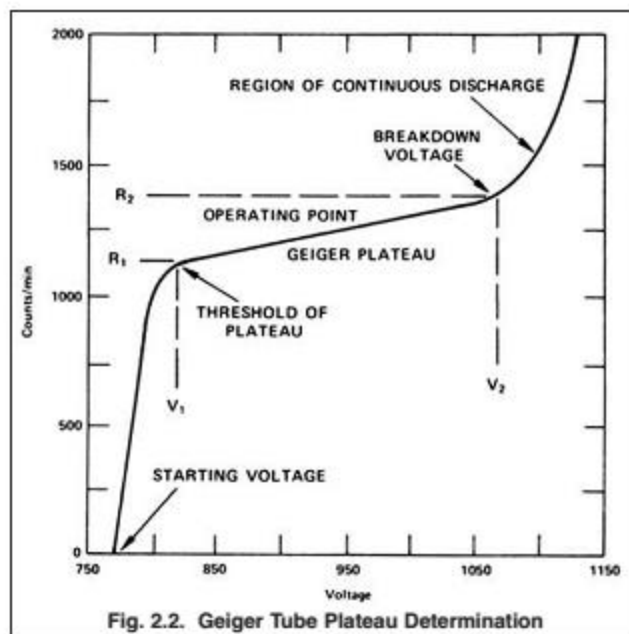


Fig. 2.2. Geiger Tube Plateau Determination

## Procedure

1. Set up the electronics as shown in Fig. 2.1. Ensure that all power is turned off.
2. On the 556 High Voltage Power Supply, set all three of the front-panel Voltage controls to their minimum value. On the rear panel, confirm that the POSITIVE POLARITY has been selected, and the CONTROL switch is set to INTERNAL.
3. Connect the cable with the MHV connector from the Geiger tube to the MHV connector labeled "GM Tube" on the GM Pulse Inverter box. Using the coaxial cable with SHV plugs, connect the high voltage OUTPUT on the rear panel of the 556 High Voltage Power
4. Using an RG-62A/U coaxial cable with BNC plugs, connect the OUTPUT on the GM Pulse Inverter box to a BNC Tee on the Channel 1 input of the oscilloscope. Connect the other side of the Tee to the POSITIVE INput on the 996 Timer and Counter using another RG-62A/U coaxial cable.
5. Set the oscilloscope to display the Channel 1 input on a vertical scale of 2 Volts per major division and a horizontal scale of  $10 \mu\text{s}$  per major division. Set the triggering mode to Auto, and select the Channel 1 input as the triggering source. Position the ground trace near the bottom of the display, and set the input coupling to DC. This setup should allow the oscilloscope to display the +4-V logic pulse from the GM Pulse Inverter.
6. Turn on power to the Bin and Power Supply and turn on power to the 556 High Voltage Power Supply.
7. On the 996 turn the THRESHold ADJUSTment screwdriver control counterclockwise until it clicks at its minimum setting. Next, turn the potentiometer clockwise 4.0 turns. This should set the POSitive INput threshold at +1.6 Volts. (The screwdriver adjustment operates a 25-turn potentiometer to set the POSitive INput threshold between +100 mV and +9.5 V.)
8. On the 996, set the TIME BASE to 0.01 MINutes. Select the PRESET time display and choose M = 3, N = 0 and P = 2. That chooses a counting time of 30 minutes.
9. Set the 996 DISPLAY to COUNTS.
10. Place the two halves of the split beta source from the source kit at a distance of  $\sim 2$  cm from the window of the Geiger tube. Depending on the manufacturer, this may be either a  $^{90}\text{Sr}/^{90}\text{Y}$  or a  $^{204}\text{Tl}$  radioactive source.<sup>2</sup> If the active source is deposited behind a thin window on one side of each plastic half-disk, make sure that the active sides are facing the end window on the Geiger counter.
11. Gradually increase the (positive) high voltage on the 556 in steps no larger than 50 V until the 996 counter just begins registering counts and the 4-V logic pulse shows up on the oscilloscope input. This point is called the starting voltage in Fig. 2.2. Starting voltages are rarely  $>900$  V and can be as low as 250 V. If the counts begin advancing on the 996 Timer and Counter, but the pulse does not show up on the oscilloscope, adjust the oscilloscope triggering. If the pulse shows up on the oscilloscope, but the



996 does not begin counting, check the setup of the 996. Basically, the oscilloscope is being used to check that the electronics are operating properly. Once proper triggering has been established, the triggering mode on the oscilloscope can be switched from Auto to Normal, with a subsequent readjustment of the triggering threshold.

12. Reset the 996 counter. Set the timer section for 1-minute time intervals, and count for 1 minute. Record the number of counts.
13. Increase the high voltage by 50 V and count again for 1 minute. Record the number of counts.

## Week 6

## Experiment # 2

### EXPERIMENT 2.2. Resolving-Time Corrections for the Geiger Counter

#### Purpose

Later experiments will be dealing with fast electronics capable of resolving sequential events spaced as closely as a few tens of nanoseconds. In stark contrast, the Geiger counter is very slow in responding to detected events. It takes of the order of a microsecond for the detector to develop its full response to the incident gamma-ray or charged particle, and it requires hundreds of microseconds to restore the detector to full sensitivity for the next event. The strict definition of the *dead time* of the Geiger counter is the time from initial response to a detected event until the detector can exhibit the earliest, albeit crippled, response to a subsequent event. But, the electronics processing the Geiger tube output pulses has a fixed voltage threshold that the pulses must exceed to be counted. Thus the *resolving time* includes the previously defined dead time, but adds the time it takes for subsequent pulses to recover to a sufficient amplitude to cross the discriminator threshold and be counted. In practice, the distinction between *dead time* and *resolving time* is often blurred, and the resolving time is frequently labeled as the dead time. That is a pragmatically empirical convention, because the measurement of counting rate is always made after the supporting electronics has added its contribution to the dead time.

The large dead time of the Geiger counter distorts the measured counting rate for counting rates above 5000 counts/minute. Thus, it is usually necessary to make a dead-time correction to obtain the true counting rate. In this experiment the measurement of the dead time will be accomplished with a split source. The measured dead time will be employed to correct the counting rates in all the subsequent measurements.

#### Relevant Equations

The dead time of a nuclear radiation counting system is typically dominated by one of two types of dead time: 1) paralyzable (a.k.a., extending) dead time, or 2) non-paralyzable (a.k.a., non-extending) dead time. For a full explanation see references 1 and 11. The dead time contributed by the Geiger counter is reasonably accurately modeled as a non-paralyzable dead time. The measured counting rate,  $R$ , is related to the true counting rate,  $r$ , at the input to the detector via equation (2).

$$R = \frac{r}{1 + rT_d} \quad (2)$$

Where  $T_d$  is the dead time caused by each quantum of radiation that is detected when the counter is free to accept a new event. Note that the dead time reduces the measured counting rate relative to the true counting rate, and higher counting rates cause a greater relative reduction.

In practice, the experimenter only has access to the measured counting rate,  $R$ , after dead time losses have occurred. Consequently, it is important to calculate the true counting rate, and this requires knowing the dead time per pulse,  $T_d$ . If equation (2) is rearranged to the form in equation (3), one can compute the true counting rate from the measured counting rate and the known dead time per pulse.

$$r = \frac{R}{1 - RT_d} \quad (3)$$

Another useful way to express the information in equations (2) and (3) is the percent dead time loss:

$$\text{Percent Dead Time} = \frac{r - R}{r} \times 100\% = RT_d \times 100\% = \frac{rT_d}{1 + rT_d} \times 100\% \quad (4)$$

One way to measure the dead time per pulse,  $T_d$ , would be to observe the output of the GM Pulse Inverter on the oscilloscope and determine the minimum spacing between the leading edges of two successive pulses. Because the arrival times of the pulses are randomly distributed in time, this method requires a fairly high counting rate to make it easy to find the minimum pulse spacing. There is a risk that the excessively high counting rate changes the dead time per pulse compared to what would be experienced at the counting rates normally used to assay the activity of radioactive samples.

The split source method has the advantage of assessing the dead time per pulse at the counting rates normally employed in assays. In this scheme, the radioactive source is contained in a circular disc that has been sectioned into two halves. Each half contains approximately the same source activity. With both halves positioned side-by-side to form the complete circular disk, the distance of the source from the window of the Geiger tube is adjusted to achieve a percent dead time in the range of 10% to 20%. For a 100- $\mu$ s dead time, this implies measured counting rates in the range of 1,000 to 2,000 counts/s, or 60,000 to 120,000 counts per minute.

Next, the first half of the source is removed, and the counting rate of the second half,  $R_2$ , is measured. Subsequently, the first half is carefully reinstalled without disturbing the second half, and the counting rate from the pair of sources,  $R_{12}$ , is measured. Finally, the second half of the disk is removed without disturbing the first half, and the counting rate,  $R_1$ , is measured.  $R_1$ ,  $R_2$ , and  $R_{12}$  can be inserted into equation (3) to write the equations for  $r_1$ ,  $r_2$ , and  $r_{12}$ , respectively. Because of the dead time,  $R_{12} < (R_1 + R_2)$ . But for the true counting rates

$$r_{12} = r_1 + r_2 \quad (5)$$



Combining equation (5) with the expressions for  $r_1$ ,  $r_2$  and  $r_{12}$  from equation (3), permits solving for  $T_d$  in terms of the measured counting rates. From reference 1, the exact solution for the case of zero background is

$$T_d = \frac{R_1 R_2 - [R_1 R_2 (R_{12} - R_1)(R_{12} - R_2)]^{1/2}}{R_1 R_2 R_{12}} \quad (6)$$

An approximate solution that is sometimes employed is

$$T_d \approx \frac{R_1 + R_2 - R_{12}}{2R_1 R_2} \quad (7)$$

## Procedure

1. Place both halves of the radioactive source split disk on the sample-holder shelf, with the disk centered below the Geiger counter window. Set the 996 Timer and Counter for a 1-minute counting interval.
2. Measure the counts for 1 minute.
3. If the number of counts in step 2 is not between 60,000 and 120,000, adjust the source to detector distance to bring the counting rate within that range by repeating steps 1 and 2.
4. Remove the left half of the split source and make a 1-minute count on the right half. Record the count. Define this count to be  $R_1$ .
5. Being careful not to disturb the right half, place the left half of the source alongside the right half and make a 1 minute count. Define this count to be  $R_{12}$ .
6. Being careful not to disturb the left half, remove the right half and count the left half for 1 minute. Define this count to be  $R_2$ . Calculate the resolving time of the Geiger tube via equation (6). The answer should be in minutes/count. Because counts are often considered a dimensionless number, the dead time can also be expressed simply in minutes or seconds.

The dead time established in step 6 should be used to correct all measured counting rates via equation (3) whenever the percent dead time exceeds 1%.

## **Linear Absorption Coefficient**

### **Purpose**

When gamma radiation passes through matter, it undergoes absorption primarily by Compton, photoelectric, and pair-production interactions. The intensity of the radiation is thus decreased as a function of distance in the absorbing medium. The purpose of this experiment is to measure the attenuation of the intensity with absorber thickness, and to derive the half-thickness and the attenuation coefficient.

### **Relevant Equations**

The mathematical expression for the surviving intensity,  $I$ , is given by the following:

$$I = I_0 e^{-\mu x} \quad (13)$$

Where

$I_0$  = original intensity of the beam,

$I$  = intensity transmitted through an absorber to a distance, depth, or thickness,  $x$ ,

$\mu$  = linear absorption coefficient for the absorbing medium.

If we rearrange Eq. (13) and take the logarithm of both sides, the expression becomes

$$\ln\left(\frac{I}{I_0}\right) = -\mu x \quad (14)$$

The half-value layer (HVL) of the absorbing medium is defined as that thickness,  $x_{1/2}$ , which will cut the initial intensity in half. That is,  $I/I_0 = 0.5$ . If we substitute this into Eq. (14),

$$\ln(0.5) = -\mu x_{1/2} \quad (15)$$

Putting in numerical values and rearranging, Eq. (15) becomes

$$x_{1/2} = \frac{0.693}{\mu} \text{ or } \mu = \frac{0.693}{x_{1/2}} \quad (16)$$

Experimentally, the usual procedure is to measure  $x_{1/2}$  and then calculate  $\mu$  from Eq. (16). If the thickness of the absorber is expressed in cm, then the units of  $\mu$  are  $\text{cm}^{-1}$ , and it is known as the linear attenuation coefficient. Often, the thickness of the absorber is expressed in  $\text{g/cm}^2$ . In that case, the attenuation coefficient has units of  $\text{cm}^2/\text{g}$ , and is identified as the mass attenuation coefficient.

## Procedure

1. Set the voltage of the Geiger tube at the operating value determined in Experiment 2.1.
2. Place the  $^{60}\text{Co}$  source about 3 cm from the window of the Geiger tube, and make a 2-minute count. Record the number of counts.
3. Note the various thicknesses of the lead sheets in the absorber kit. They may all be of equal thickness, or they may have nominal thicknesses of 1,000  $\text{mg/cm}^2$ , 2,000  $\text{mg/cm}^2$ , 3,000  $\text{mg/cm}^2$  and 7,000  $\text{mg/cm}^2$ . This experiment will require a total thickness ranging from 1,000  $\text{mg/cm}^2$  to circa 23,000  $\text{mg/cm}^2$  in 1,000 to 2,000  $\text{mg/cm}^2$  steps. Incrementing the total thickness will require using the various foils in suitable combinations to achieve the desired thickness increments.
4. Place the thinnest sheet of lead from the absorber kit between the source and the GM tube window and take another 2-minute count. Record the value.
5. Add a second sheet of lead on top of the first to increase the total thickness by a value between 1,000 and 2,000  $\text{mg/cm}^2$ , and make another count.
6. Continue inserting combinations of lead sheets to increment the total thickness in steps of 1,000 to 2,000  $\text{mg/cm}^2$  until the number of counts is 25% of the number recorded with no absorber. Record the counts taken in 2 minutes for each step in the total absorber thickness.
7. Correct the measured counts for dead time whenever the dead time losses are calculated to be  $>1\%$ .
8. Make a 2-minute background run with the  $^{60}\text{Co}$  source removed to a long distance from the counting station, and subtract this value from each of the above counts that have been corrected for dead time. Check this background count at the maximum absorber thickness employed and without any absorbers. The result should be the same, or close enough to the same that the average of the two background readings can be used for background subtraction from all the corrected counting rates with the source in the counting position.

## Objectives of the Experiment

The behaviour of the Hall voltage in a sample of doped germanium is studied in three different set-ups as follows:

1. Constant control current and temperature and varying magnetic field.
2. Constant magnetic field and temperature and varying control current.
3. Constant magnetic field and control current and varying temperature.

From these measurements the sign of the charge carriers, the Hall constant, the carrier mobility and the carrier concentration can all be determined.

## Theory

### The Drude model of electron conduction

The relationship between the current flowing in a conducting medium and the applied voltage is given by Ohm's law which states

$$V = IR$$

This very simple law applies to a very wide range of materials such as metals, semiconductors, electrolytic solutions, weakly ionized gases etc. In metals it also applies over a very wide range of current densities from 100 amp/m<sup>2</sup>. At 10<sup>13</sup> amp/m<sup>2</sup> the deviation from Ohm's law is only 1%.

The conducting medium may be viewed as an assembly of atoms through which the charge carriers move when an electric field is applied to the medium. The charge carriers, whether they be electrons, ionized atoms or positive holes have thermal energy of

$$\frac{3}{2}kT$$

where  $k$  is Boltzmann's constant and  $T$  is the absolute temperature. If  $m$  is the mass of the charge carriers then the thermal velocity ( $\bar{v}$ ) of the carriers may be obtained from

$$\frac{1}{2} m \bar{v}^2 = \frac{3}{2} kT \quad (20.1)$$

The flow of current through a metal wire may be pictured as follows:

The atoms are all bound into the crystal lattice. Each atom readily loses its valence electrons so that if a voltage is applied to the wire these valence electrons move along the electric field lines with a directed velocity, superimposed on their random thermal velocity. The electrons are accelerated by the electric field but periodically they collide with an atom of the crystal lattice and, as a result of the collision, lose the directed velocity acquired from the electric field. This fluctuating velocity directed along the field lines, distinct from the thermal velocity, is called the drift velocity,  $v_d$  and is given by:

$$v_d = a \tau \quad (20.2)$$

where  $a$  is the acceleration of the electrons and  $\tau$  is the mean time between collisions, related to the mean free path,  $\lambda$ , by :

$$\tau = \frac{\lambda}{\bar{v}} \quad (20.3)$$

From Newton's 2nd law :

$$a = \frac{E.e}{m} \quad (20.4)$$

where

$E$  is the electric field strength

$e$  is the charge on the electron

and  $m$  is the mass of the electron.

Substituting Eqs. 20.3 and 20.4 into Eq. 20.2 we get:

$$v_d = \frac{E.e}{m} \frac{\lambda}{\bar{v}} \quad (20.5)$$

Electron mobility ( $\mu$ ) is defined as :

$$\mu = \frac{e \lambda}{m \bar{v}} \quad (20.6)$$

and

$$\mu = \frac{e}{m} \tau \text{ from Eq. 20.3}$$

The mobility is thus the drift velocity acquired by an electron per unit electric field and

$$v_d = \mu E \quad (20.7)$$

The drift of the electron in response to the applied voltage (electric field) gives rise to a current  $I$  given by :

$$I = neAv_d \quad (20.8)$$

where:

$n$  is the number of electrons per unit volume

$A$  is the cross-sectional area of the conductor.

Hence using Eq. 20.7:

$$I = neA\mu E \quad (20.9)$$

If  $l$  is the length of the conductor, the voltage across it is:

$$V = El \quad (20.10)$$

From Ohm's law and Eqs. 20.9 and 20.10 the resistance  $R$  is given by:

$$R = \frac{V}{I} = \frac{El}{neA\mu E}$$

$$R = \frac{l}{neA\mu} \quad (20.11)$$

$R$  can also be written in terms of the dimensions of the conductor and its resistivity  $\rho$

$$R = \frac{\rho l}{A} \quad (20.12)$$

Combining Eqs. 20.11 and 20.12 gives:

$$\rho = \frac{1}{ne\mu} \quad (20.13)$$

**Week 9**

**Experiment # 3**

## The Hall Effect

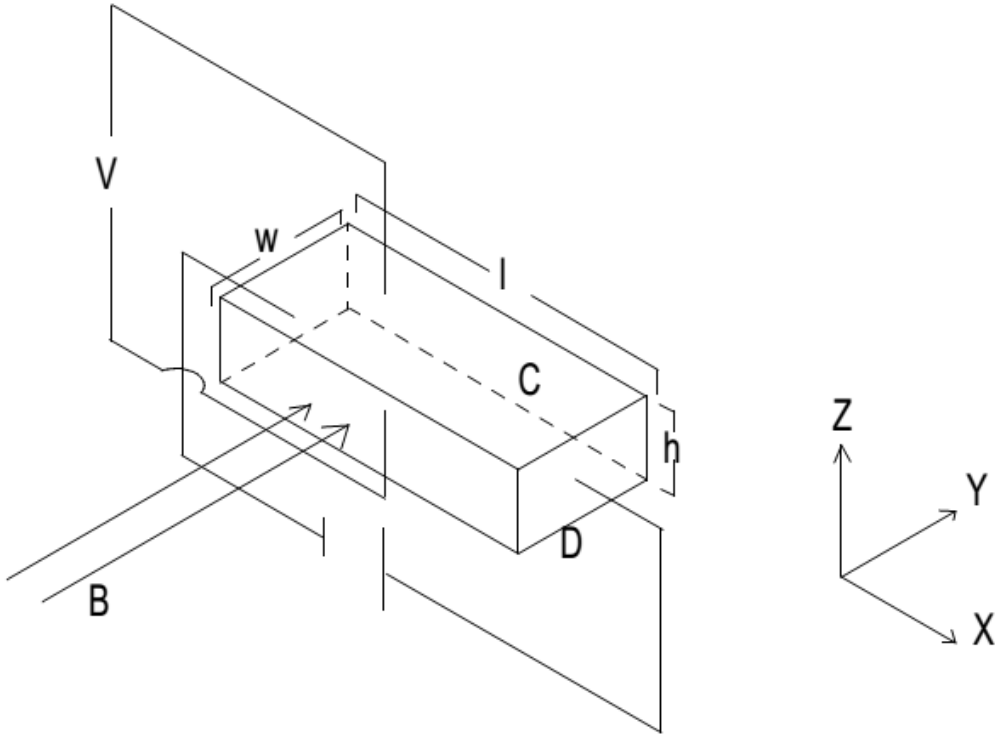
The Hall effect was first observed by an American scientist, E. H. Hall, in 1879. It is illustrated in Fig. 20.1. If a current passes through a conducting material along the X direction and there is a magnetic field in the Y direction then a voltage difference  $V_H$  appears along the Z axis, that is between the faces C & D of the material. If a charge  $e$  moves with velocity  $v_d$  through a magnetic field  $B$  then a force  $\vec{F}$  acts on the charge, where

$$\vec{F} = e\vec{v}_d \times \vec{B} \quad (20.14)$$

If the charge moves along the X-axis and the magnetic field is along the Y axis then the force is along the Z axis. If the charges are positive then the force acts in the direction of the positive Z axis. Positive charges will therefore move upwards towards face C and because an excess charge accumulates on face C with a corresponding shortage on face D, a voltage, the Hall voltage, develops in the Z direction. The Hall voltage increases until it exactly balances the force due to the magnetic field and equilibrium is reached. Hence,

$$ev_d B = \frac{eV_H}{h}$$

$$V_H = v_d B h \quad (20.15)$$



where  $h$  is the thickness of the crystal in the Z-direction. This can be written in terms of the current making use of Eq. 20.8. Hence,

$$V_H = \frac{hBI}{neA} \quad (20.16)$$

From Fig. 20.1 the cross section area (A) is

$$A = wh$$

$$V_H = \frac{BI}{new} \quad (20.17)$$

The Hall constant is defined as :

$$R_H = \frac{1}{ne} \quad (20.18)$$

Substituting Eq. 20.18 in Eq.20.17

$$V_H = \frac{R_H B}{w} I \quad (20.19)$$

Eq. 20.19 can be written as follows :

$$R_H = \frac{V_H w}{IB} \quad (20.20)$$

From Eq. 20.17 it can be seen that the Hall voltage changes linearly with magnetic field and such a 'Hall probe' device is often used to measure magnetic fields. It is not practical to use metals in such devices as  $n$  is very large for these materials, making  $V_H$  very small. Of course for insulating materials, such as glass,  $n$  is very small but very large voltages are then required to increase  $I$  to

some measurable value. It was not until the manufacture of semi-conducting materials that the value of  $n$  could be set to its optimum value and the device then became a convenient method of measuring magnetic fields.

## The Hall effect in semiconductors

Semiconductors have important characteristics which have led to their crucial role in the electronics revolution of the last 50 years. Although they have lower room temperature conductivity than metals, their conductivity increases as temperature increases, unlike metals, and both electrons and positive carriers ('holes') may contribute to the conductivity (see experiment on the PN junction for more details). Semiconductors can be chemically 'doped' so that there is an excess of either electrons ('n-type') or holes ('p-type') participating in conduction. Doping alters the conductivity of the semiconductor and offers many possibilities to control the behaviour of the material and is the main reason for the importance of semiconductors in modern electronic devices.

The relative contribution of electrons and holes to the conductivity changes as a function of temperature and the behaviour of the Hall voltage with temperature can be used to examine the type of charge carriers which dominate in different temperature regions.



## Experimental Set-up and Procedure

A schematic diagram of the experimental set-up is shown in Fig. 20.2a.

The heater circuit is not required until Part 2 of the experiment.

The Hall crystal is a sample of either p-type or n-type germanium (depending on the apparatus being used) mounted on a plug-in board and attached to the base unit. The crystal is extremely fragile and the plug-in board should not be removed from the base unit.

The magnetic field surrounding the sample is provided by the electromagnet through which a current is passed from PSU 1. The value of the magnetic field near the sample is monitored using a Hall probe which is a precalibrated sensor that is connected via the B-box to the CASSY interface for computerised recording. The probe is very delicate and should be moved carefully into position along the rail provided so that the probe tip is mid-way along the sample.

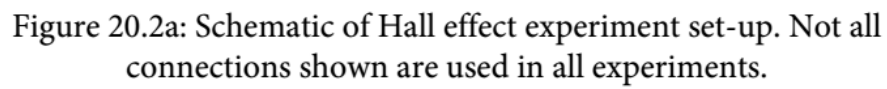
Power supply unit 1 (PSU1) also provides the current to the sample as shown in Fig. 20.2a. The current is measured using a multimeter in series. A connection to the CASSY interface for computerised recording can be made as required.

The Hall voltage generated is measured across the sample using a multimeter in parallel. A connection to the CASSY interface for computerised recording can be made as required.

### Part 1

In this part of the experiment there are 3 parameters of interest: current in the sample, magnetic field in the sample and Hall voltage generated. We wish to explore how the Hall voltage varies with each parameter separately, keeping the other constant and hence verify (or disprove!) the predictions of the classical model described in Section 20.

Firstly, set the circuit up as shown in Fig. 20.2a and carefully set the sample current using the 'current adjust' control on the base unit to a value of  $\sim 30$  mA. Record this current value and



## Experiment # 3

## Data Analysis

From Eq. 20.19 the Hall voltage should vary linearly as a function of magnetic field or sample current. Is this prediction borne out by your data? Determine the slopes of your graphs and use Eq. 20.19 to make 2 independent estimates of the Hall coefficient,  $R_H$ , of your sample.

The width of the sample,  $w$ , is 1 mm.

What are the dominant sources of error on your results? Use the propagation of errors formula and justifiable order of magnitude estimates of the error on each measured quantity to derive an overall percentage error for each  $R_H$  value. Do not go into excessive mathematical detail. Do your two estimates of  $R_H$  agree to within the errors?

Use Eq. 20.18 to determine  $n$ , the number of charge carriers per unit volume in the sample.

Note: Undoped germanium at room temperature has  $\sim 2 \times 10^{19}$  carriers per  $\text{m}^3$ . How does your value compare with this?

Measure the resistance of the sample in the absence of the magnetic field. Using Eq. 20.12 determine  $\rho$  and hence  $\mu$  (Eq. 20.13) and  $\tau$ .

Note:  $l = 0.02 \text{ m}$ ,  $A = 1.0 \times 10^{-5} \text{ m}^2$ .

Use the following values of the constants  $m$  and  $e$ :

$$m = 9.1 \times 10^{-31} \text{ Kg}$$

$$e = 1.6 \times 10^{-19} \text{ Coulomb}$$

Choosing some value of  $I$  used during the determination of  $R_H$ , estimate the drift velocity  $v_d$  (Eq. 20.8) of the charge carriers.