e/m By Thomson Method

Nvis 6103

Learning Material

Ver 1.2

An ISO 9001: 2008 company

Designed & Manufactured in India by :

Nvis Technologies Pvt. Ltd.

141-A, Electronic Complex, Pardesipura, Indore - 452 010 India

Tel.: 91-731-4211500, E-mail: info@nvistech.com, Website : www.NvisTech.com

CERTIFICATE OF COMPLIANCE

INTERNATIONAL CERTIFICATION SERVICES PVT. LTD.

This is to certify that the
QUALITY MANAGEMENT SYSTEM of

NVIS TECHNOLOGIES PVT. LTD.

141-A, Electronic Complex, Pardesipura, Indore - 452 010,
Madhya Pradesh, India.

has been assessed and registered as complying with the requirements of the following International Standard:

ISO 9001:2015

The Quality Management System applicable to:

Scope : Design And Manufacture Of Didactic Products And Clean Technologies Products Such As Solar Solutions.

Registration No. : RQ91/7763
Registered Date : 17th June, 2012
Reassessment Date : 28th June, 2018
Issue Date : 30th June, 2018
Expiry Date : 16th June, 2021

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e/m By Thomson Method

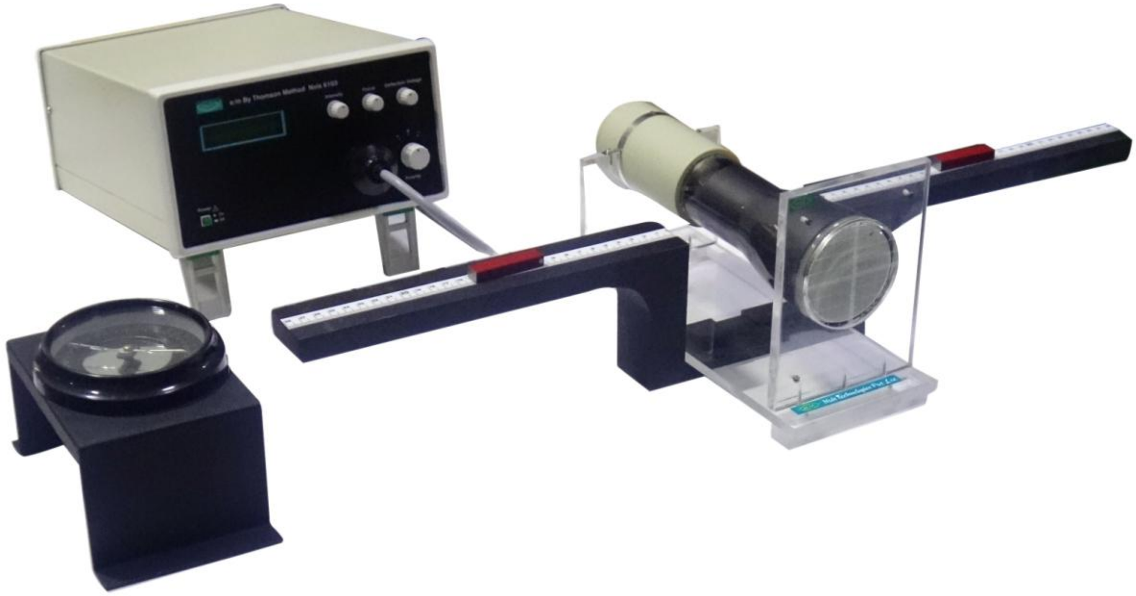
Nvis 6103

Table of Contents

Introduction

Nvis 6103 e/m By Thomson Method setup is very useful for physics and basic science laboratories. This is used to find the specific charge ratio of an electron particle in a CRT by Thomson method using bar magnet. This system is provided with a Power Supply unit for CRT and Deflection Magnetometer with stand arrangement and mounting stand for CRT. Nvis 6103 have a microcontroller based instrument with LCD display for displaying deflection voltage. It is highly secure and stable system. J.J Thomson was the first scientist who measured charge to mass ratio (e/m) of an electron. When a narrow beam of charged particles are projected at constant speed (v) across a magnetic field in a direction perpendicular to the field, the beam of particles experiences a force, which make them move in a circular path.

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



Features

- **Microcontroller Based Measurement and Power Supply**
- **LCD display to measure Deflection Voltage**
- **Focusing Adjustment**
- **Intensity Adjustment**
- **Cathode Ray Tube mounting on Acrylic Stand**
- **Deflection Magnetometer provided**
- **Provided with Pair of Bar Magnet**

Technical Specifications

Cathode Ray Tube:

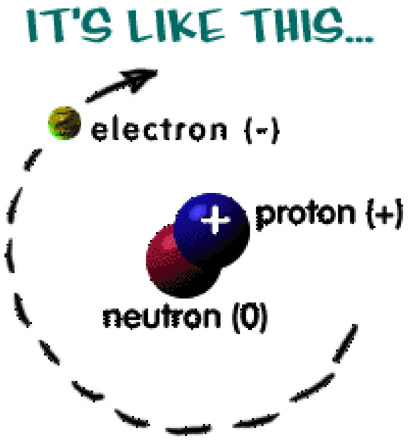
Distance between plates (d)	:	2.85 cm
Length of plates (*l*)	:	3.15 cm
Distance between screen and plates (L)	:	12 cm
CRT connection with power supply	:	Octal socket
Deflection voltage	:	Variable 0 to 55 Volt
Scale	:	0 to 25 cm each side
LCD	:	16×2 Characters
Deflection magnetometer	:	0 to 90^0 (Four Quadrant)
Mains	:	230 VAC ± 10%, 50 Hz
Fuse	:	500 mA

Theory

In e/m method we are working on electron beam before knowing an electron beam we must know the atom and electron

Atomic Theory

All matter is made up of very tiny particles called atoms. Atoms of the same element are chemically alike individual atoms of an element may not all have the same mass. However, the atoms of an element have a definite average mass that is characteristic of the element. Atoms of different elements have different average masses. Atoms are not subdivided, created, or destroyed in chemical reactions.



There are three parts of an atom: protons, neutron, and electrons. Protons have a positive charge, electrons have a negative charge, and neutrons possess no net charge.

Electrons are the smallest parts of the atom. They are the most numerous of the three. It has no known components or substructure, so it is an elementary particle. Its mass is 1/1836 of a proton. It is also considered to be fermions. It has an antiparticle called the positron. The positron is identical to the electron except that it carries opposite charge. When an electron collides with a positron, both particles will either scatter or be destroyed producing gamma ray photons. Electrons can collide with other particles and be diffracted like light. Two electrons cannot occupy the same quantum state based on the Pauli Exclusion Principle.

The proton is the part of an atom that helps to form the nucleus and has a positive charge. Protons must have an equal number of neutrons except int eh hydrogen atom where a single proton exists on its own. A proton is composed of 2 up quarks and one down quark. They are considered to be fermions and baryons. They are held together by the strong nuclear force. The number of protons in the nucleus of an atom determines the atomic number.

A neutron is the part of an atom that holds no charge. Neutrons and protons occur in equal numbers in stable atoms except in hydrogen. Protons and neutrons are often referred to together as nucleons. If there are more neutrons than protons, then the atom is considered an isotope. If an neutron becomes free of its proton, then it becomes unstable, undergoes beta decay, and will disintegrate in an average of 15 minutes. The neutron is also important in nuclear chain reactions: both natural and artificial.

Sizes of Atoms

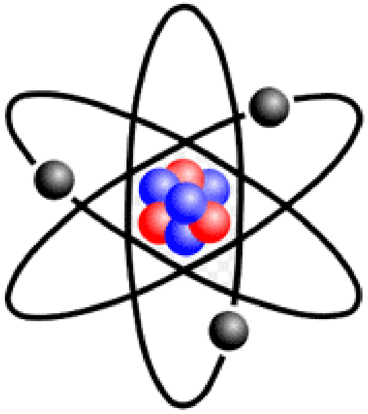
- Atomic radius

1. 40 to 270 picometers (pm), **a.** 1 pm = 10-12m
2. Most of the atomic radius is due to the electron cloud

- B. Nuclear radius

1. 0.001 pm
2. Density is 2x108 metric tons/cm3
  a. 1 metric ton = 1000kg

Atomic Model



Electrons orbit the nucleus at set distances. When an electron changes orbits, it does so in a sudden quantum leap. The energy difference between the initial and final orbit is emitted by the atom in bundles of electromagnetic radiation called photons. This model was proposed in 1913 by Niels Bohr and was really an expansion on the Rutherford model of 1911.

Development of the Atomic Theory

Atom – The smallest particle into which an element can be divided and still be the same substance.
Element – A pure substance that cannot be separated into simpler substances by physical or chemical means.

- Atoms make up elements.
- Elements are made of only one kind of atom.
- Elements combine to form compounds.

- All matter is made of elements or compounds, so all matter is made of atoms.
- Atoms are so small that, until recently, no one had ever seen one. But ideas, or theories, about atoms have been around for over 2,000 years.

Theory – A unifying explanation for a broad range of hypotheses and observations that have been supported by testing.

Democritus (440 B.C.)

- Democritus proposed that if you kept cutting a substance in half forever, eventually you would end up with an “uncuttable” particle. He called these particles atoms, meaning “indivisible” in Greek.
- Democritus thought that atoms were small, hard particles of a single material and in different shapes and sizes.
- He thought that atoms were always moving and formed different materials by combining with each other.
- Aristotle disagreed with Democritus’s idea that you would end up with an indivisible particle. Because Aristotle had greater public influence, Democritus’s ideas were ignored for centuries.

John Dalton (1803)

Scientists knew that elements combined with each other in specific proportions to form compounds. Dalton claimed that the reason for this was because elements are made of atoms. He published his own three-part atomic theory:

1) All substances are made of atoms. Atoms are small particles that cannot be created, divided, or destroyed.

2) Atoms of the same element are exactly alike, and atoms of different elements are different.

3) Atoms join with other atoms to make new substances.

Much of Dalton’s theory was correct, but some of it was later proven incorrect and revised as scientists learned more about atoms.

J.J. Thomson (1897)

Thomson used a cathode-ray tube to conduct an experiment which showed that there are small particles inside atoms. This discovery identified an error in Dalton’s atomic theory. Atoms can be divided into smaller parts. Because the beam moved away from the negatively charged plate and toward the positively charged plate, Thomson knew that the particles must have a negative charge. He called these particles corpuscles. We now call these particles electrons. Electrons – The negatively charged particles found in all atoms. Thomson changed the atomic theory to include the presence of electrons. He knew there must be positive charges present to balance the negative charges of the electrons, but he didn’t know where. Thomson proposed a model of an atom called the “plum-pudding” model, in which negative electrons are scattered throughout soft blobs of positively charged material.

Ernest Rutherford (1909)

Rutherford conducted an experiment in which he shot a beam of positively charged particles into a sheet of gold foil. Rutherford predicted that if atoms were soft, as the plum-pudding model suggested, the particles would pass through the gold and continue in a straight line. Most of the particles did continue in a straight line. However some of the particles were deflected to the sides a bit, and a few bounced straight back. Rutherford realized that the plum pudding model did not explain his observations. He changed the atomic theory and developed a new model of the atom. Rutherford's model says that most of the atom's mass is found in a region in the center called the nucleus. Nucleus – The tiny, extremely dense, positively charged region in the center of an atom. Rutherford calculated that the nucleus was 100,000 times smaller than the diameter of the atom. In Rutherford's model the atom is mostly empty space, and the electrons travel in random paths around the nucleus.

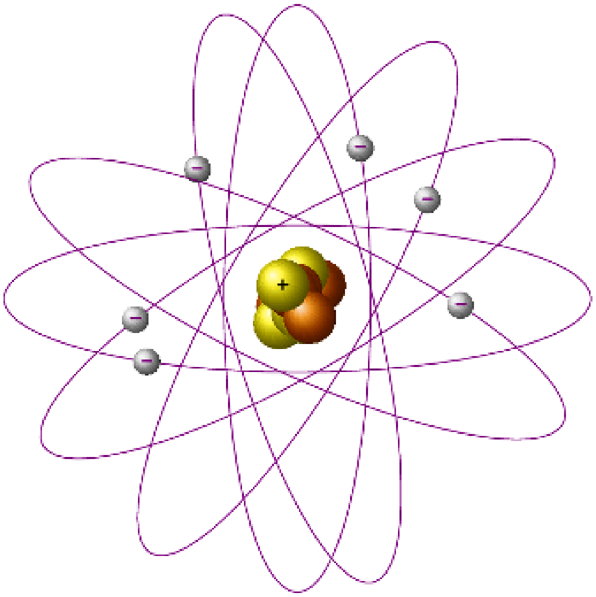
Niels Bohr (1913)

Bohr suggested that electrons travel around the nucleus in definite paths. These paths are located at certain "levels" from the nucleus. Electrons cannot travel between paths, but they can jump from one path to another.

Modern Theory

Schrödinger and Heisenberg

Our current model of the atom says that electrons do not travel in definite paths around the nucleus. The exact path or position of moving electron cannot be predicted or determined. Rather, there are regions inside the atom were electrons are likely to be found. Electron clouds – Regions inside an atom where electrons are likely to be found.



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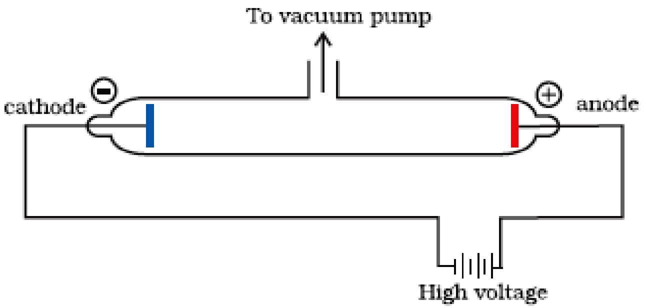
Courtesy By:
http://tex.stackexchange.com/questions/73410/draw-bohr-atomic-model-with-electron-shells-in-tex

Discovery of Electron

In 1830, Michael Faraday showed that if electricity is passed through a solution of an electrolyte, chemical reactions occurred at the electrodes, which resulted in the liberation and deposition of matter at the electrodes. These results suggested the particulate nature of electricity.

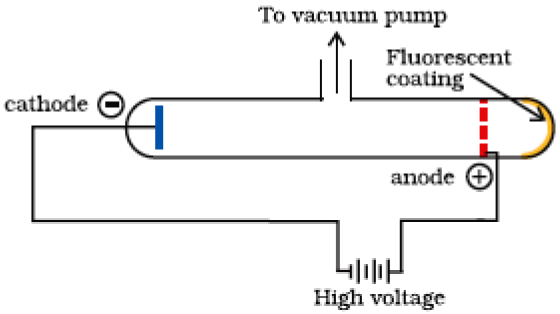
An insight into the structure of atom was obtained from the experiments on electrical discharge through gases. Before we discuss these results we need to keep in mind a basic rule regarding the behaviour of charged particles: “Like charges repel each other and unlike charges attract each other”.

In mid 1850s many scientists mainly Faraday began to study electrical discharge in partially evacuated tubes, known as cathode ray discharge tubes. It is depicted in Fig.



A cathode ray discharge tube

A cathode ray tube is made of glass containing two thin pieces of metal, called electrodes, sealed in it. The electrical discharge through the gases could be observed only at very low pressures and at very high voltages. The pressure of different gases could be adjusted by evacuation. When sufficiently high voltage is applied across the electrodes, current starts flowing through a stream of particles moving in the tube from the negative electrode (cathode) to the positive electrode (anode). These were called cathode rays or cathode ray particles. The flow of current from cathode to anode was further checked by making a hole in the anode and coating the tube behind anode with phosphorescent material zinc Sulphide. When these rays, after passing through anode, strike the zinc Sulphide coating, a bright spot on the coating is developed (same thing happens in a television set) Fig 4.



A cathode ray discharge tube with perforated anode

In 1897, British physicist J.J. Thomson measured the ratio of electrical charge (e) to the mass of electron (me) by using cathode ray tube and applying electrical and magnetic field perpendicular to each other as well as to the path of electrons (Fig. 2.2). Thomson argued that the amount of deviation of the particles from their path in the presence of electrical or magnetic field depends upon:

(i) the magnitude of the negative charge on the particle, greater the magnitude of the charge on the particle, greater is the interaction with the electric or magnetic field and thus greater is the deflection.

(ii) the mass of the particle — lighter the particle, greater the deflection.

(iii) the strength of the electrical or magnetic field — the deflection of electrons from its original path increases with the increase in the voltage across the electrodes, or the strength of the magnetic field.

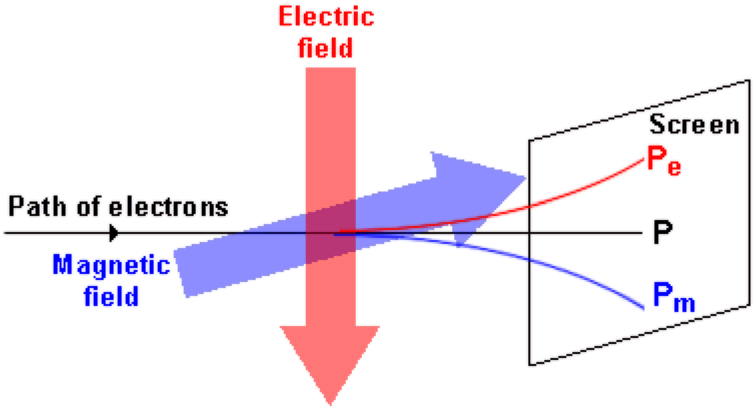
When only electric field is applied, the electrons deviate from their path and hit the cathode ray tube at point A. Similarly when only magnetic field is applied, electron strikes the cathode ray tube at point C. By carefully balancing the electrical and magnetic field strength, it is possible to bring back the electron to the path followed as in the absence of electric or magnetic field and they hit the screen at point B. By carrying out accurate measurements on the amount of deflections observed by the electrons on the electric field strength or magnetic field strength, Thomson was able to determine the value of e/m_e as:

$e/m_e = 1.758820 \times 10^{11}$ C kg^{-1}

Where me is the mass of the electron in kg and e is the magnitude of the charge on the electron in coulomb (C). Since electrons are negatively charged, the charge on electron is -e.

The charge to mass ratio for the electron

J. J. Thomson determined the charge (**e**) to mass (**m**) ratio, **e/m** for the electron, using an apparatus which applied perpendicular electric and magnetic fields of known magnitude to a beam of electrons.



In the absence of any applied electric and magnetic fields, a beam of electrons (which are negatively charged) will not be deflected, and continue on a straight path, to be detected at point P on the screen. If an electric field is applied, the electrons will be deflected and detected at the point P_e. In the presence of the magnetic field alone, the electrons will be deflected downwards and be detected at the point P_m.

Now, if both fields are switched on, they can be adjusted so that there is no deflection, in other words, the electrons will hit the screen at point P. This occurs when the two fields exert equal and opposite forces on the electrons. Then, it can be shown that

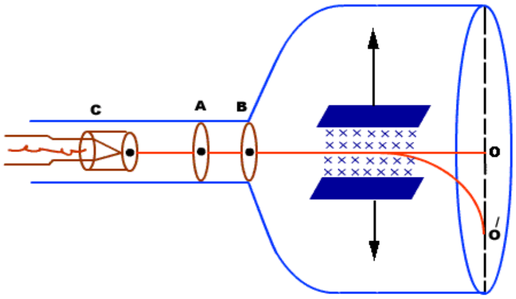
$$\mathbf{e/m = E^2/2VB^2}$$

Where **E** and **B** are the known strengths of the electric and magnetic fields respectively, and **V** the known potential difference between the charged parallel plates that produce the electric field.

Bear in mind that this experiment does not give individual values for either the mass or the charge on the electron!

CRT

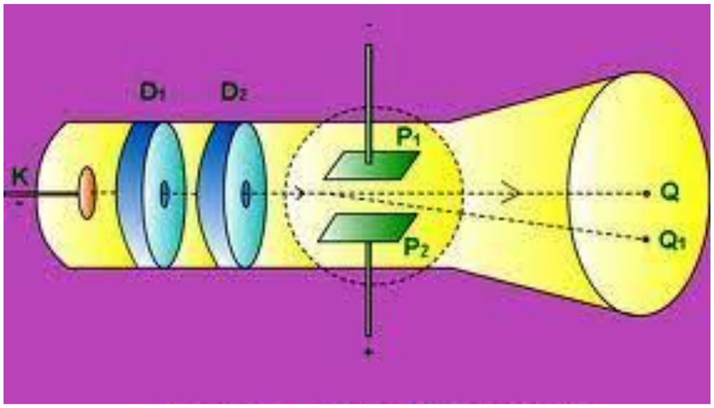
The Cathode-Ray Tube (CRT) is one of the main elements of an oscilloscope. The tubes are produced with electrostatic and electromagnetic control, where electrostatic or magnetic fields deviate the electron beam respectively. CRT consists of the glass bulb evacuated to a high vacuum, the cathode (a source of electrons), cathode heater, electrodes for brightness and focus control, several accelerating anodes, the pairs of horizontal and vertical capacitor plates deviating the electron beam, and fluorescing screen. One of anodes, which accelerate the electrons, is placed close to the screen. The high positive voltage is applied to this electrode. Under the action of the applied voltage the electrons move with acceleration from cathode to anode. In the absence of the voltage applied to deviating plates of the capacitor the electron beam will be incident on the screen in the center brightening a point in the fluorescing layer. In oscilloscope the analyzed signal after amplification is applied to vertical deviating plates, while the periodic saw tooth signal is applied to horizontal plates. As a result the electron beam "draws" the dependence of the investigated signal on time on the screen of the tube. Reaching the right side of the screen the beam has to be returned to an initial point at the left side. Thus, if CRT is not blanked during this retrace, then the beam will leave a track crossing the image of investigated signal. For this reason, during retrace a negative voltage is applied to control electrode situated near to cathode and electrons are locked by such a way at the electron gun.



The earliest version of the CRT was a cold-cathode diode, a modification of the Crookes tube with a phosphor-coated screen, sometimes called a Braun tube. The first version to use a hot cathode was developed by John B. Johnson (who gave his name to the term Johnson noise) and Harry Weiner Weinhart of Western Electric, and became a commercial product in 1922. The cathode rays are now known to be a beam of electrons emitted from a heated cathode inside a vacuum tube and accelerated by a potential difference between this cathode and an anode. The screen is covered with a phosphorescent coating (often transition metals or rare earth elements), which emits visible light when excited by high-energy electrons. The beam is deflected either by a magnetic or an electric field to move the bright dot to the required position on the screen. In television sets and computer monitors the entire front area of the tube is scanned systematically in a fixed pattern called as raster. An image is produced by modulating the intensity of the electron beam with a received video signal (or another signal derived from it). In all CRT TV receivers except some very early models, the beam is deflected by magnetic deflection, a varying magnetic field generated by coils (the magnetic yoke), driven by electronic circuits, around the neck of the tube.

Electron Gun

The source of the electron beam is the electron gun, which produces a stream of electrons through thermionic emission, and focuses it into a thin beam. The gun is located in the narrow, cylindrical neck at the extreme rear of a CRT and has electrical connecting pins, usually arranged in a circular configuration, extending from its end. These pins provide external connections to the cathode, to various grid elements in the gun used to focus and modulate the beam, and, in electrostatic deflection CRTs, to the deflection plates. Since the CRT is a hot-cathode device, these pins also provide connections to one or more filament heaters within the electron gun. When a CRT is operating, the heaters can often be seen glowing orange through the glass walls of the CRT neck. The need for these heaters to 'warm up' causes a delay between the time that a CRT is first turned on, and the time that a display becomes visible. In older tubes, this could take fifteen seconds or more; modern CRT displays have fast-starting circuits which produce an image within about two seconds, using either briefly increased heater current or elevated cathode voltage. Once the CRT has warmed up, the heaters stay on continuously. The electrodes are often covered with a black layer, a patented process used by all major CRT manufacturers to improve electron density.



The electron gun accelerates not only electrons but also ions present in the imperfect vacuum (some of which result from out gassing of the internal tube components). The ions, being much heavier than electrons, are deflected much less by the magnetic or electrostatic fields used to position the electron beam. Ions striking the screen damage it; to prevent this electron gun can be positioned slightly off the axis of the tube so that the ions strike the side of the CRT instead of the screen. Permanent magnets (the ion trap) deflect the lighter electrons so that they strike the screen. Some very old TV sets without an ion trap show browning of the center of the screen, known as ion burn. The aluminum coating used in later CRTs reduced the need for an ion trap.

When electrons strike the poorly-conductive phosphor layer on the glass CRT, it becomes electrically charged, and tends to repel electrons, reducing brightness (this effect is known as "sticking"). To prevent this interior side of the phosphor layer can be covered with a layer of aluminum connected to the conductive layer inside the tube, which disposes of this charge. It has the additional advantages of increasing brightness by reflecting towards the viewer light emitted towards the back of the tube, and protecting the phosphor from ion bombardment.

Oscilloscope Tubes

For use in an oscilloscope, the design is somewhat different. Rather than tracing out a raster, the electron beam is directly steered along an arbitrary path, while its intensity is kept constant. Usually the beam is deflected horizontally (X) by a varying potential difference between a pair of plates to its left and right, and vertically (Y) by plates above and below, although magnetic deflection is possible. The instantaneous position of the beam will depend upon the X and Y voltages. It is most useful for the horizontal voltage, repeatedly, to increase linearly with time until the beam reaches the edge of the screen, then jump back to its starting value (sawtooth waveform, generated by a timebase). This causes the display to trace out the Y voltage as a function of time. Many oscilloscopes only function in this mode. However it can be useful to display, say, the voltage versus the current in an inductive component with an oscilloscope that allows X-Y input, without using the timebase.

The electron gun is always centered in the tube neck; the problem of ion production is either ignored or mitigated by using an aluminized screen.

The beam can be moved much more rapidly, and it is easier to make the beam deflection accurately proportional to the applied signal, by using electrostatic deflection as described above instead of magnetic deflection. Magnetic deflection is achieved by passing currents through coils external to the tube; it allows the construction of much shorter tubes for a given screen size. Circuit arrangements are required to approximately linearize the beam position as a function of signal current and the very wide deflection angles require arrangements to keep the beam focussed (dynamic focussing).

In principle either type of deflection can be used for any purpose; but electrostatic deflection is best for oscilloscopes with relatively small screens and high performance requirements, while a television receiver with a large screen and electrostatic deflection would be many meters deep. Some issues must be resolved when using electrostatic deflection. Simple deflection plates appear as a fairly large capacitive load to the deflection amplifiers, requiring large current flow to charge and discharge this capacitance rapidly. Another, more subtle, problem is that when the electrostatic charge switches, electrons which are already part of the way through the deflection plate region will only be partially deflected. This results in the trace on the screen lagging behind a rapid change in signal.

Extremely high performance oscilloscopes avoid these problems by subdividing the vertical (and sometimes horizontal) deflection plates into a series of plates along the length of the "deflection" region of the CRT, and electrically joined by a delay line terminated in its characteristic impedance; the timing of the delay line is set to match the velocity of the electrons through the deflection region. In this way, a change of charge "flows along" the deflection plate along with the electrons that it should affect, almost negating its effect on those electrons which are already partially through the region. Consequently the beam as seen on the screen slews almost instantly from the old point to the new point. In addition, because the entire deflection system operates as a matched-impedance load, the problem of driving a large capacitive load is mitigated.

It is very common for oscilloscopes to have amplifiers which rapidly chop or swap the beam, blanking the display while switching. This allows the single beam to show as two or more traces, each representing a different input signal. These are properly called multiple-trace (dual trace, quadruple trace, etc.) oscilloscopes.

Much rarer is the true dual beam oscilloscope, whose tube contains an electron gun that produces two independent electron beams. Usually, but not always, both beams are deflected horizontally by a single shared pair of plates, while each beam has its own vertical deflection plates. This allows a time-domain display to show two signals simultaneously.

Many modern oscilloscope tubes pass the electron beam through an expansion mesh. This mesh acts like a lens for electrons and has the effect of roughly doubling the deflection of the electron beam, allowing the use of a larger faceplate for the same length of tube envelope. The expansion mesh also tends to increase the "spot size" on the screen, but this tradeoff is usually acceptable.

When displaying one-shot fast events the electron beam must deflect very quickly, with few electrons impinging on the screen, leading to a faint or invisible display. A simple improvement can be attained by fitting a hood on the screen against which the observer presses his face, excluding extraneous light, but oscilloscope CRTs designed for very fast signals give a brighter display by passing the electron beam through a micro-channel plate just before it reaches the screen. Through the phenomenon of secondary emission this plate multiplies the number of electrons reaching the phosphor screen, giving a brighter display, possibly with a slightly larger spot.

The phosphors used in the screens of oscilloscope tubes are different from those used in the screens of other display tubes. Phosphors used for displaying moving pictures should produce an image which fades very rapidly to avoid smearing of new information by the remains of the previous picture; i.e., they should have short persistence. An oscilloscope will often display a trace which repeats unchanged, so longer persistence is not a problem; but it is a definite advantage when viewing a single-shot event, so longer-persistence phosphors are used. An oscilloscope trace can be any colour without loss of information, so a phosphor with maximum effective luminosity is usually used. The eye is most sensitive to green: for visual and general-purpose use the P31 phosphor gives a visually bright trace, and also photographs well and is reasonably resistant to burning by the electron beam. For displays meant to be photographed rather than viewed, the blue trace of P11 phosphor gives higher photographic brightness; for extremely slow displays, very-long-persistence phosphors such as P7, which produce a blue trace followed by a longer-lasting amber or yellow afterimage, are used. The phosphor screen of most oscilloscope tubes contains a permanently-marked internal graticule, dividing the screen using Cartesian coordinates. This internal graticule allows for the easy measurement of signals with no worries about parallax error. Less expensive oscilloscope tubes may instead have an external graticule of glass or acrylic plastic. Most graticules can be side-illuminated for use in a darkened room.

Oscilloscope tubes almost never contain integrated implosion protection. External implosion protection must always be provided, either in the form of an external graticule or, for tubes with an internal graticule, a plain sheet of glass or plastic. The implosion protection shield is often coloured to match the light emitted by the phosphor screen; this improves the contrast as seen by the user.

The Glass Envelope

The outer glass allows the light generated by the phosphor out of the monitor, but (for colour tubes) it must block dangerous X-rays generated by high energy electrons impacting the inside of the CRT face. For this reason, the glass is leaded. Colour tubes require significantly higher anode voltages than monochrome tubes (as high as 32,000 volts in large tubes), partly to compensate for the blockage of some electrons by the aperture mask or grille; the amount of X-rays produced increases with voltage. Because of leaded glass, other shielding, and protective circuits designed to prevent the anode voltage from rising too high in case of malfunction, the X-ray emission of modern CRTs is well within approved safety limits.

CRTs have a pronounced triode characteristic, which results in significant gamma (a nonlinear relationship between beam current and light intensity). In early televisions, screen gamma was an advantage because it acted to compress the screen contrast. However in systems where linear response is required (such as when desktop publishing), gamma correction is applied. The gamma characteristic exists today in all digital video systems. CRT displays accumulate a static electrical charge on the screen, unless preventive measures are taken. This charge does not pose a safety hazard, but can lead to significant degradation of image quality through attraction of dust particles to the surface of the screen. Unless the display is regularly cleaned with a dry cloth or special cleaning tissue (using ordinary household cleaners may damage anti-glare protective layer on the screen), after a few months the brightness and clarity of the image drops significantly. The high voltage (EHT) used for accelerating the electrons is provided by a transformer. For CRTs used in televisions, this is usually a flyback transformer that steps up the line (horizontal) deflection supply to as much as 32,000 volts for a colour tube, although monochrome tubes and special CRTs may operate at much lower voltages. The output of the transformer is rectified and the pulsating output voltage is smoothened by a capacitor formed by the tube itself (the accelerating anode being one plate, the glass being the dielectric, and the grounded (earthed) Aquadag coating on the outside of the tube being the other plate). Before all-glass tubes, the structure between the screen and the electron gun was made from a heavy metal cone which served as the accelerating anode. Smoothing of the EHT was then done with a high voltage capacitor, external to the tube itself. In the earliest televisions, before the invention of the flyback transformer design, a linear high-voltage supply was used; because these supplies were capable of delivering much more current at their high voltage than flyback high voltage systems – in the case of an accident they proved extremely deadly. The flyback circuit design addressed this: in the case of a fault, the flyback system delivers relatively little current, improving a person's chance of surviving a direct shock from the high voltage anode.

High Voltage

CRTs operate at very high voltages, which can persist long after the device containing the CRT has been switched off and/or unplugged, sometimes for years. Residual charges of hundreds of volts can also remain in large capacitors in the Power Supply circuits of the device containing the CRT; these charges may persist. Modern circuits contain bleeder resistors, to ensure that the high-voltage supply is discharged to safe levels within a couple of minutes at most. These discharge devices can fail even on a modern unit and leave these high voltage charges present. The final anode connector on the bulb of the tube carries this high voltage.

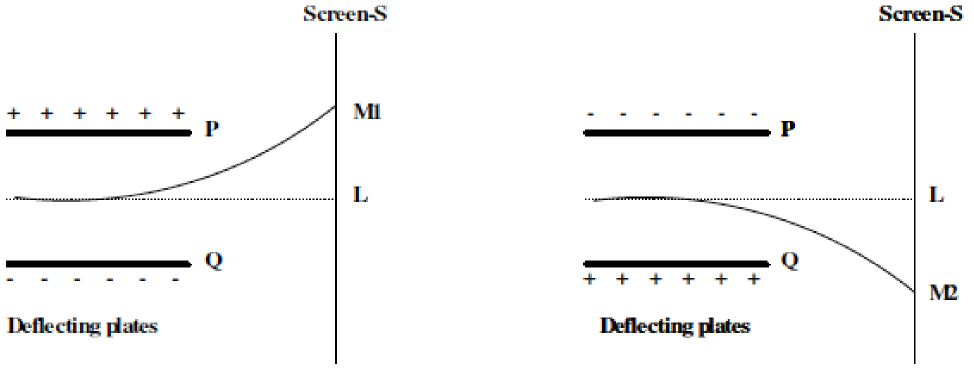
Electron

An electron is a subatomic particle. Carrying a negative charge, an electron orbits an atom’s nucleus and is bound to it by electromagnetic forces. An electron has a mass that is minuscule in comparison with even the smallest of atoms, coming in at about one thousandth the size of the tiniest atom. The electron is a basic unit of nature, meaning it cannot be broken down into smaller units.

The electron plays a starring roll in many of the interactions we see on a daily basis. For example, electrons are partially responsible for the fact that we can stand on a flat surface and not sink right through it. This occurs as the result of the mutual repulsion of the electrons in both the ground and a person’s shoes. We also depend on electrons for electrical current to power electronic devices. Even televisions rely on electrons to function properly.

If an electric field, E, is applied between the two plates perpendicular to the direction of electron beam passing through the space between the plates, the force acting on an electron in the upward direction of motion is given by [2,3]
$F = eE$ …………. (1)
where F is the force acting on an electron,
e is the electronic charge =1.6x10-19Coulomb, and E is the applied electric field.

Because of the applied electric field, electrons travel in a semicircular path and strike the screen at the point M1. By reversing the polarity of the voltage applied to the plate, electrons can be moved in the downward direction in a semicircular path as shown in Figure .



Deflection of electron beam by an electric filed

Instead of electric field if we apply a magnetic field perpendicular to the direction of electron flow, similar deflection of the beam takes place by reversing the magnetic field in which case also the direction of the beam gets reversed similar to the deflection caused by the electric field. If r is the radius of the semicircular path traversed by an electron in the magnetic field, the force acting on the electron is given by

$$Bev = \frac{mv^2}{r} \quad \ldots\ldots\ldots\ldots (2)$$

where B is the applied magnetic field,
v is the velocity of the electron at the point where it enters the magnetic field,and r is the radius of the circular path traversed by the electron.

From above Equation, e/m is given by

$$\frac{e}{m} = \frac{v}{Br} \quad \ldots\ldots\ldots.. (3)$$

In order to determine the ratio e/m, one needs to know the value of the magnetic field applied, the velocity of the electron, and radius of semicircular path traced by the electron.

Determination of electron velocity (v)

With the application of electric field, the electron beam moves to position M1 as shown in above Figure. Now the magnetic field is applied so that the beam deflects back to its original position at O. When the magnetic force is equal to the electric force, the beam comes back to its original position. Hence one can write

$$Bev = eE$$

$$V = \frac{E}{B}$$

$$\frac{e}{m} = \frac{E}{B^2 r} \quad \ldots\ldots.. (4)$$

Thus the electron velocity is equal to the ratio of the two applied fields which is known.
Hence v can be determined.

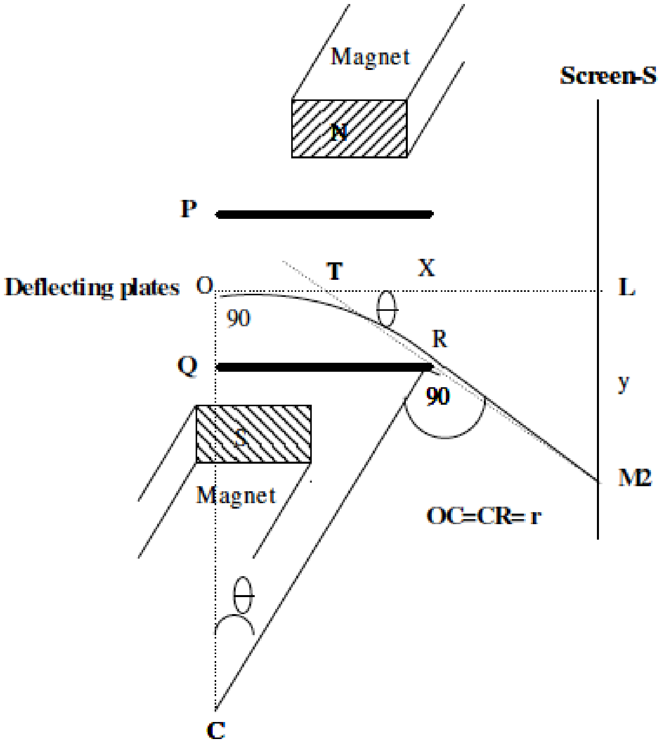
Determination of radius (r) of the semicircular path traced by the electron beam

In order to determine the radius, r, one needs to consider the geometry of electron path as shown in below Figure. An electron entering between the pair of plates PQ at O will trace an arc and leave the plates at R and then move in a straight line path and strike the screen at the point M2. OA is the path traced by the electron when there is no applied field. The line joining the electron path after leaving the plates is extrapolated to meet the OA line at T. Two perpendicular lines OC and RC are drawn to meet at C which forms the circle of radius r. OC and CR are two perpendicular lines drawn to meet at C. From the geometry one can write.

$\angle OCR = \angle ATM2 = \theta$

$$Tan\theta = \frac{AM_2}{AT} = \frac{OX}{OC}$$

$$r = OC = \frac{AT * OX}{AM_2}$$



Geometry of the electron path

If L is distance between the screen and center of the two parallel plates,

AT= L

OX is the length of the parallel plates

OX= l

LM2 = y is the distance the spot moves on the screen, which can be measured on the graduated screen of the CRT. Hence

$$r = \frac{L1}{y}$$

Substituting for radius and velocity, e/m is given by

$$\frac{e}{m} = \frac{yE}{L1B^2}$$

If V is the voltage applied between the two parallel plates and d is the separation between them, then

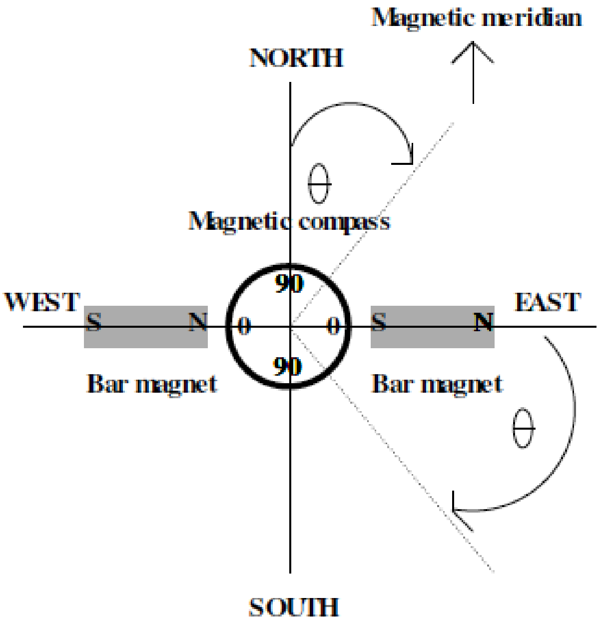
$$E = \frac{V}{d}$$

Hence

$$\frac{e}{m} = \frac{V_y}{dL1B^2}$$

Measurement of magnetic field (B)

The magnetic field at the center of the two plates P and Q, cannot be measured using a gauss meter because the magnetic field produced by bar magnets is of the order of 10-3 Tesla which is quite low. Hence conventional methods are used for this. The magnetic field strength, B,can be calculated knowing the pole strength and dimensions of the bar magnet or by the well-known method using a magnetometer which does not need information on any dimensional parameters of the magnet. In this method the bar magnets are placed perpendicular to the earth’s magnetic field, as shown in the below Figure. The CRT is aligned parallel to the earth’s magnetic meridian in which case the electron beam travels parallel to the magnetic meridian.



Magnetic compass used for measuring magnetic field

The magnetic field strength at the center of the compass due to a bar magnet is given by

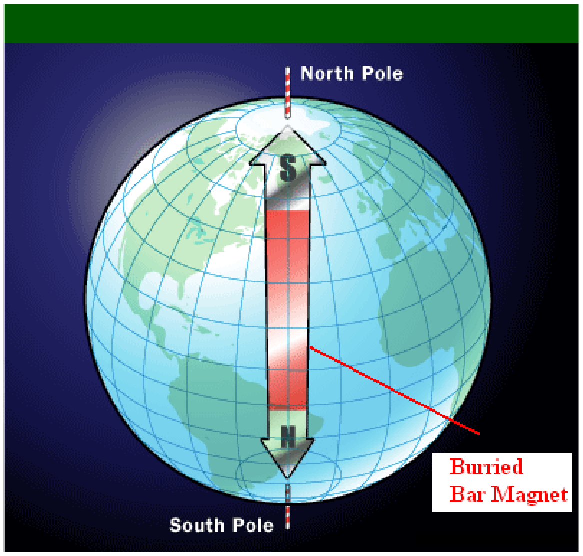
B = H tanθ

where H is earth’s magnetic field =3.81 x 10-5T at Bangalore, and θ is the angle of deflection of the compass needle.

Compass (Deflection Magnetometer)

A compass is an extremely simple device. It consists of a small, light weight magnet balanced on a nearly frictionless pivot point. The magnet is generally called a needle. One end of the needle is often marked "N," for north, or coloured in some way to indicate that it points toward north. Generally red colour is used to indicate north.

The reason why a compass works is more interesting. It turns out that you can think of the Earth as having a gigantic bar magnet buried inside. In order for the north end of the compass to point toward the North Pole, you have to assume that the buried bar magnet has its south end at the North Pole, as shown in the below figure. If you think of the world this way, then you can see that the normal "opposites attract" rule of magnets would cause the north end of the compass needle to point towards the south end of the buried bar magnet. So the compass points towards the North Pole.



Bar Magnet imagined as buried inside Earth

To be completely accurate, the bar magnet does not run exactly along the Earth’s rotational axis. It is skewed slightly off center. This skew is called the declination, and most good maps indicate what the declination is in different areas (since it changes a little depending on where you are on the planet).

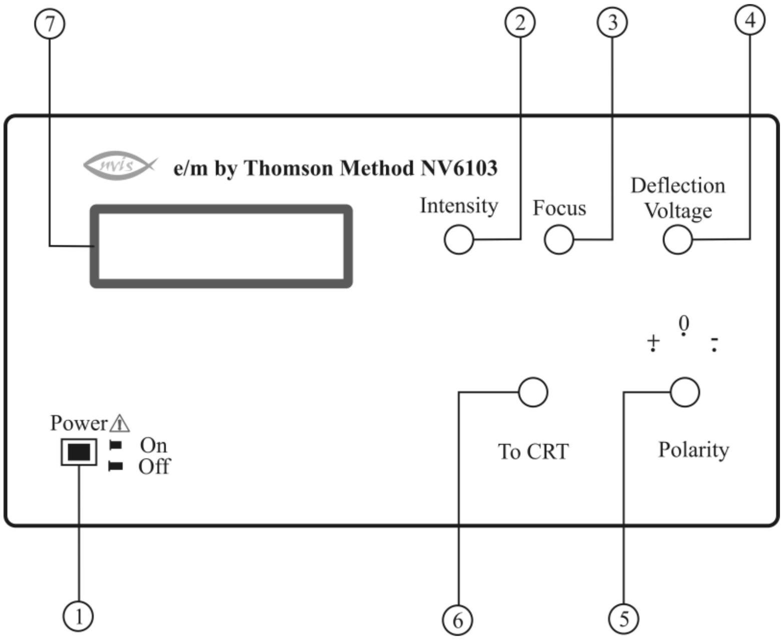
The magnetic field of the Earth is fairly weak on the surface. After all, the planet Earth is almost 8,000 miles in diameter, so the magnetic field has to travel a long way to affect your compass. That is why a compass needs to have a light weight magnet and a frictionless bearing. Otherwise, there just isn’t enough strength in the Earth’s magnetic field to turn the needle.

It turns out that because the Earth’s magnetic field is so weak, a compass is nothing but a detector for very slight magnetic fields created by anything. That is why we can use a compass to detect the small magnetic field produced by a wire carrying a current.

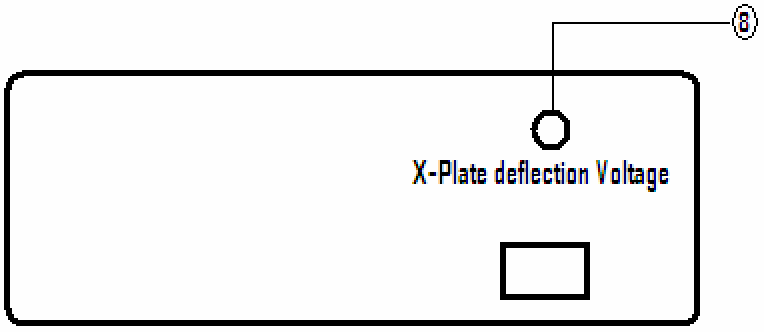
The “big bar magnet buried in the core” analogy works to explain why the Earth has a magnetic field, but obviously that is not what is really happening.

Measurement Unit

Front Panel Controls



Rear Panel Control



1. **Power:** It is used to switch on/off the instrument.
2. **Intensity:** It controls the intensity of spot.
3. **Focus:** it controls the sharpness of the spot.
4. **Deflection Voltage:** With the help of it Y – plate deflection voltage can be adjusted.
5. **Polarity:** It is three position rotary switches to select direction of spot deflection. It has three positions, + for upward – for downward and 0 in centre position.
6. **To CRT:** Octal base provided to connect CRT.
7. **Liquid Crystal Display:** To display DC voltage value applied to plates.
8. **X-Plate Deflection Voltage:** With the help of it X- plate deflection voltage can be adjusted.

Precautions: CRT can break handle it with care.

Experiment

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

Items Required

1. Deflection Magnetometer
2. Two Bar Magnets
3. CRT
4. Stand Arrangement

Theory

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

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

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

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

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

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

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

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

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

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

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

Thus $$Ee = B\,e\,v$$

… 5

Or $$v = \frac{E}{B}$$

….6

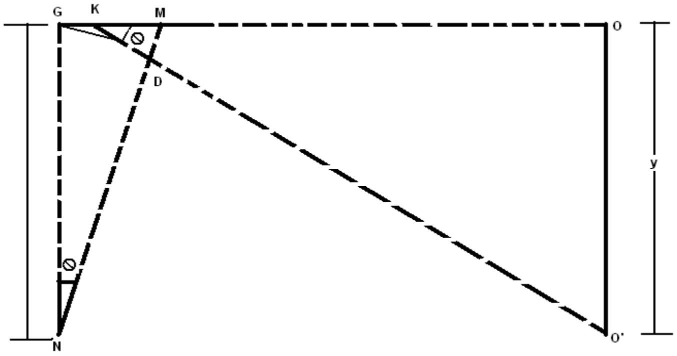
Substituting values of v from 6 into 4

$$e/m = E/B^2r \qquad ….7$$

Radius 'r':

According to the figure below, the original electron beam is preceding straight path G, M, O and impressed upon screen at a point O. In the presence of magnetic field, the beam travels along a circular arc G, D whose radius is r. beyond point D, the beam leave magnetic field and proceeds straight in direction along with the tangent K, DO' (drawn on the circular arc at point D). Drawing GN normal to GKO and MDN normal to KDO'. Let these normal meet at point N. Then GN = ND = r = the radius of circular arc. Let GND = $OK0' = \theta$

Then in angle KOO'…… $\tan\theta = \frac{00'}{K0}$ and the angle θ is small enough,



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

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

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

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

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

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

Substituting values of r into …7,

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

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

Therefore,
$$\frac{e}{m} = \frac{Vy}{B^2 lLd}$$
… 10

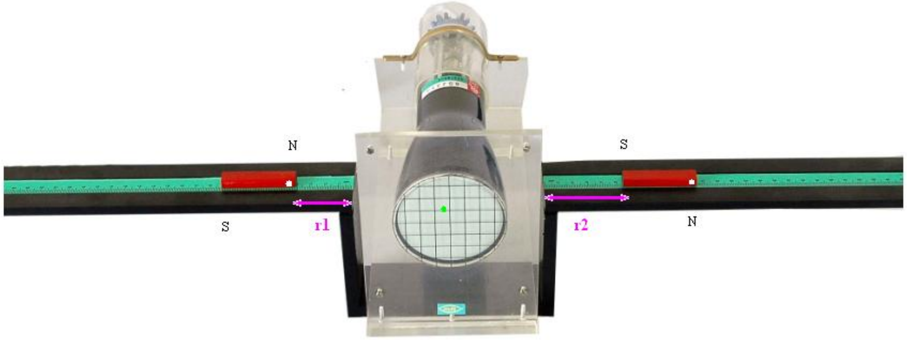
Where y = distance between spot positions displayed on the screen of CRT in centimeters.

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

Procedure:

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

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



Adjust position of magnets to get spot back downward to original position.

12. Note the distances of bar magnet (poles facing the screen) as $\mathbf{r_1}$ and $\mathbf{r_2}$ from the scale.

13. Now remove magnets from the arms of stand.

14. Select '–' **position** from polarity switch. Apply DC voltage to deflect the spot 1 cm away in downward direction. Note deflection voltage from display as **V2** and deflection as y.

15. Place bar magnets again and adjust the position of magnets to bring spot back to original position. Note the distance of the magnets (poles facing the screen) as $\mathbf{r_1}'$ and $\mathbf{r_2}'$.

16. Remove CRT and magnets. Place Magnetometer arrangement in between stand such that its centre lies on the center of the stand arm.

Note: Position of stand should not be disturbed.

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

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

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

20. Now we know that magnetic field

$$B = H \tan \theta$$

Where

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

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

21. Calculate e / m using following formula

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

Where

- $H = \sim 0.37 \times 10^{-4}$ Tesla
- Distance between plates, $d = 2.85$ cm $= 2.85 \times 10^{-2}$ m
- Length of plates, $l = 3.15$ cm $= 3.15 \times 10^{-2}$ m
- Distance between screen and plates, $L = 12$ cm $= 12 \times 10^{-2}$ m

- V = deflection voltage **(V1+V2)/2**
- Deflection of spot, y = 1cm = 1×10^{-2} m
  Deflection Voltage Deflection in cm **y** = 1cm

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

23. Calculate the % error as

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

Precautions and sources of error:

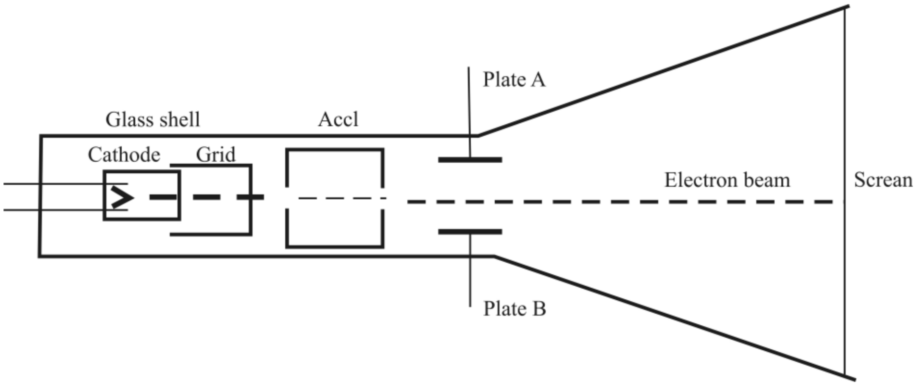
- The cathode ray tube should be handled carefully. There should not be any magnetic substance nearby the place of experiment.
- Axis of magnets and axis of tube should lie perpendicular to each other in same horizontal plane. To correct it loose the neck clamp of CRT and rotate CRT so the spot deflects right up/down with deflection voltage.
- When magnets are place upon the arms. It is better to move stand slightly back & forth to obtain maximum magnetic field at deflecting plates. It should be done before bringing spot back to original position.
- Rotate magnet (s) on there axis if spot does not come back to its original position.
- When direction of spot is reversed the direction of magnets should also be reversed.
  The magnets should move tight to the scale in closest possible distances.
- The electric field between plates cannot be uniform due to shorter distance between them.
- The given constants are generally taken from data; there may be slight variations to produce error.

Specification of given CRT:

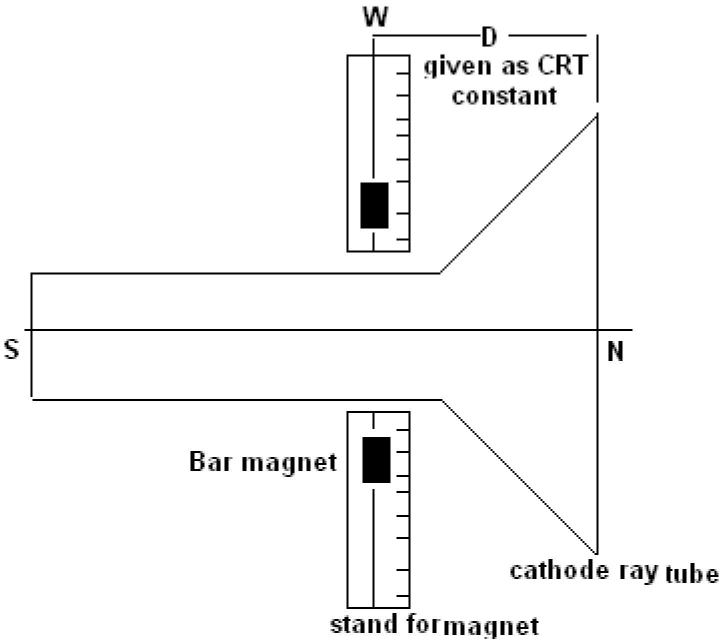
- Distance between plates, : d = 2.85 cm
- Length of plates : l = 3.15 cm
- Distance between screen and plates (edge) : L = 12 cm

Standard Value of e/m:

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



Cathode ray tube used in Thomson method



Way to place cathode ray tube

Sample Reading

Experiment

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

Formula Used :

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

Standard values :

- H = ~0.37×10^{-4} Tesla
- Distance between plates, d = 2.85 cm = 2.85×10^{-2} m
- Length of plates, l = 3.15 cm = 3.15×10^{-2} m
- Distance between screen and plates, L = 12 cm = 12×10^{-2} m
- V = deflection voltage
- Deflection of spot, y = 1cm = 1×10^{-2} m

Calculated value :
V = 15.2 Volt
$\theta 1 = 76^0$
$\theta 2 = 73^0$
$\theta 3 = 60^0$
$\theta 4 = 60^0$

Formula used for calculation :-

Formula for calculation Value of magnetic field

$$B = H \tan \theta$$

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

Putting the values of θ in above formula,

we have

$$\theta = \frac{76+73+60+60}{4}$$

It gives, $\theta = 67.25^0$

Now putting value of θ for calculating B

$B = 0.37 \times 10^{-4} \times \tan(67.25^0)$

$= 0.37 \times 2.38 \times 10^{-4}$

$= 0.880 \times 10^{-4}$ Tesla

Formula for calculating e/m ratio

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

Substituting all the above values to determine the e/m ratio

$$\frac{e}{m} = \frac{15.2 \times 1 \times 10^{-2}}{(0.880 \times 10^{-4})^2 \times 3.15 \times 10^{-2} \times 12 \times 10^{-2} \times 2.85 \times 10^{-2}}$$

On solving the above equation we have

e/m = 1.82×10^{11} C/Kg

Standard value of **e/m =** 1.75×10^{11} C/Kg

Calculation of Percentage Error

$$\frac{\text{(Standard value – calculated value) x 100}}{\text{Standard value}}$$

% Error = $\frac{1.75 - 1.82}{1.75}$ x 100

% Error = 4 %

Glossary

Atomic Number. The number of protons in an atom's nucleus, which distinguishes it from the atoms of other elements.

Atoms. The smallest particles that exhibit the unique characteristics of that particular element.

Magnetic Field. A condition found in the region around a magnet or an electric current, characterized by the existence of a detectable magnetic force at every point in the region and by the existence of magnetic poles.

Static magnetic fields. They are magnetic fields that do not vary with time (frequency of 0 Hz).

Magnetometer. An instrument for measuring the strength and sometimes the direction of a magnetic field.

Gauss. Unit of measure of magnetic induction, B, or flux density in the CGS system.

Magnetic Orientation. Determines the magnetic polarity and position of one magnet pole to the other.

Magnetic Saturation. The maximum amount of magnetic energy that can be absorbed by a magnetic substance.

North Pole. That magnetic pole which attracts the geographic North Pole.

Oersted. The unit of magnetic intensity in the cgs (centimeter-gram-second) system that describes magnetic force.

Frequently Asked Questions

Q1.How are magnets made?

Ans. Modern magnet materials are made through casting, pressing and sintering, compression bonding, injection molding, extruding, or calendaring processes.

Q2. How permanent is a magnet's strength?

Ans. If a magnet is stored away from power lines, other magnets, high temperatures, and other factors that adversely affect the magnet; it will retain its magnetism essentially forever.

Q3. Will magnets lose their power over time?

Ans. Modern magnet materials do lose a very small fraction of their magnetism over time. For Samarium Cobalt materials, for example, this has been shown to be less that 1% over a period of ten years.

Q4. What are Magnetic Poles?

Ans. Magnetic Poles are the surfaces from which the invisible lines of magnetic flux emanate and connect on return to the magnet.

Q5. How can you tell which is the North Pole if it is not marked?

Ans. You can't tell by looking. You can tell by placing a compass close to the magnet. The end of the needle that normally points toward the North Pole of the Earth would point to the South Pole of the magnet.

Q6. What are Rare Earth Magnets?

Ans. Rare Earth magnets are magnets that are made out of the Rare Earth group of elements. The most common Rare Earth magnets are the Neodymium-Iron-Boron and Samarium Cobalt types.

Q7. Which are the strongest magnets?

Ans. The most powerful magnets available today are the Rare Earths types. Of the Rare Earths, Neodymium-Iron-Boron types are the strongest. However, at elevated temperatures (of approximately 150°C and above), the Samarium Cobalt types can be stronger that the Neodymium-Iron-Boron types (depending on the magnetic circuit).

Q8. What about the earth’s magnetic field?

Ans. That is a static magnetic field which people have lived in for millions of years. It is not the same as ELF magnetic fields which have only recently become widespread at high levels since man-made AC electrical power has been in use.

Q9. What are Electric and Magnetic Fields?

Electric and magnetic fields (EMFs) are present wherever electricity flows — around appliances and power lines, and in offices, schools and homes.

- **Electric fields** are invisible lines of force created by voltage. Voltage is the electric force that causes current in a conductor, and is shielded by most materials.
- **Magnetic fields** are invisible lines of force created by current, movement of lectrons in a conductor. They are not shielded by most materials such as lead, soil and concrete.

Q10. How are Milligauss and Microtesla Related?

Ans. 1 microtesla = 10 milligauss

- 1 Gauss = 1,000 milligauss
- 1 Tesla = 1,000,000 microtesla

Q11. What effect does a magnetic field have on a charged particle?

Ans. A magnetic field alters the direction a charged particle is traveling. This is true if the charged particle is moving "across" and not "along" the magnetic lines of force of the field through which it is moving. The particle is said to be deflected when it (the particle) passes through magnetic field lines.

Warranty

1) We warranty the product against all manufacturing defects for 12 months from the date of sale by us or through our dealers. Consumables like dry cell etc. are not covered under warranty.

2) The warranty will become void, if

  a) The product is not operated as per the instruction given in the learning material.

  b) The agreed payment terms and other conditions of sale are not followed.

  c) The customer resells the instrument to another party.

  d) Any attempt is made to service and modify the instrument.

3) The non-working of the product is to be communicated to us immediately giving full details of the complaints and defects noticed specifically mentioning the type, serial number of the product and date of purchase etc.

4) The repair work will be carried out, provided the product is dispatched securely packed and insured. The transportation charges shall be borne by the customer.

Note: CRT is not covered in the warranty.

List of Accessories

1. Bar Magnet set……………………………………………………………………1 No.
2. Magnetic Deflection Meter……………………………………………………….1 No.
3. Measurement Unit…………………………………………………………..1 No.
4. CRT …………………………………………………………………...1 No.
5. Mains Cord………………………………………………………………….1 No.
6. U-shaped graduated stand ……………………………………………….1 No.

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