HECKATHORN

PHYSICS OF TECHNOLOGY —A Modular Approach

THE CATHODE RAY TUBE

A MODULE ON ELECTRIC FIELDS AND FORCES

PRINCIPAL AUTHORS: Arnold Benton
American Institute of Physics
Ludwig P. Lange
Broome Community College

PROJECT DIRECTORS: Carl R. Stannard
Bruce E. Marsh

SUNY
State University of New York at Binghamton

Coordinated by the American Institute of Physics

<u>TABLE OF CONTENTS</u>

MATHEMATICS PREREQUISITES

1. Trigonometry - ability to use sin, cos, tan
2. Addition of vectors
3. Ability to use exponential notation

LAWS AND PRINCIPLES TO BE EXTRACTED

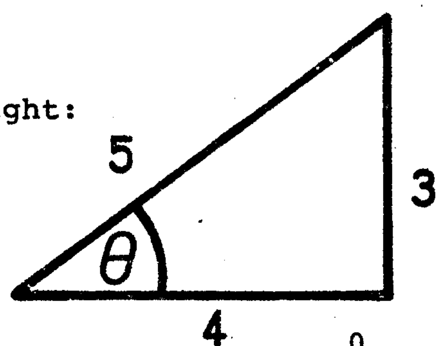
1. Conservation of charge
2. Coulomb's Law
3. Concept of a field
4. Force on a charged particle in an electric field
5. Application of Newton's Second Law to charged particles moving in uniform electric fields

PREREQUISITES CHECK

If you are to be successful in your study of this module, there are some things you should know and be able to do before you begin. Try to answer the following questions. If you can handle them all easily, you should be able to read the module and do the experiments without difficulty. If you have trouble with any of these questions, ask your instructor for help on those items before you begin to study the module.

A. Mathematical Skills

1. For the right triangle at the right:



(a) $\sin\theta$ =

(b) $\cos\theta$ =

(c) $\tan\theta$ =

2. A man walks 4 miles east, then he walks 4 miles 60^0 north of west. Where is he in relation to his starting point?

3. Write as a number between 1 and 10 multiplied by the proper power of ten:

(a) 12,400

(b) 0.00309

4. Carry out the indicated calculations:

$$\frac{3 \times 10^{10} \times 6 \times 10^{-27}}{9 \times 10^{-19}}$$

B. Vocabulary

1. The following words are used in connection with forces on an object and the motion that may result. Can you define them?

   (a) force
   (b) attract
   (c) repel
   (d) deflect
   (e) mass
   (f) velocity
   (g) acceleration
   (h) average
   (i) constant
   (j) uniform

2. The following words are used in connection with work done by a force and the changes in energy which may result. Can you define them?

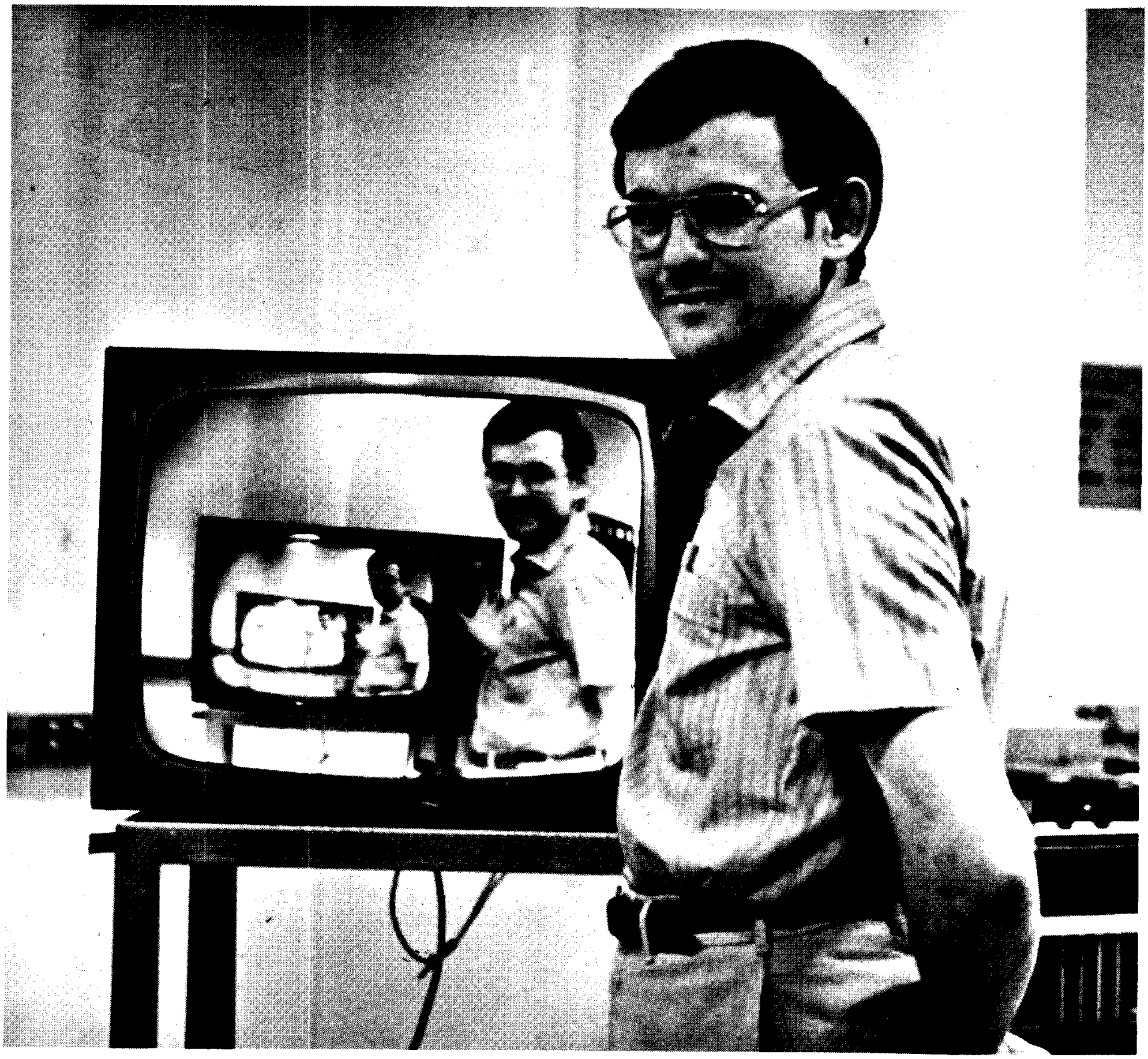
   (a) work
   (b) energy
   (c) kinetic energy
   (d) potential energy
   (e) conservation
   (f) joule
   (g) microjoule

3. The following words are used in connection with vectors. Can you define them?

   (a) vector
   (b) component
   (c) magnitude
   (d) tangent
   (e) parallel
   (f) perpendicular

4. The following words are used in connection with electrical apparatus. Can you define them?

   (a) electricity
   (b) terminal
   (c) electrode
   (d) cathode
   (e) battery
   (f) oscilloscope
   (g) deflecting plates
   (h) banana plug
   (i) AC
   (j) DC



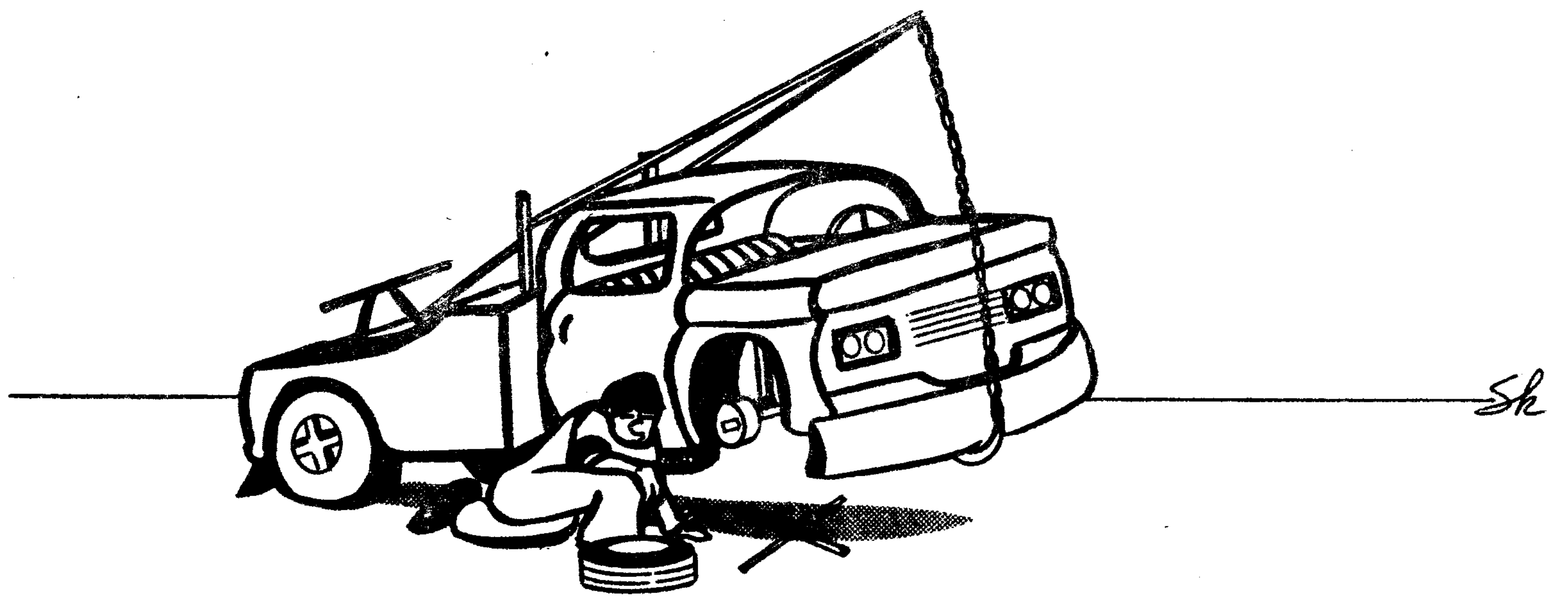
You are using a cathode ray tube whenever you watch television. The picture is formed by 525 horizontal scans of the electron beam. Each scan takes about 0.000063 seconds (63 microseconds). The signal from the TV camera causes the intensity of the beam in the viewer's CRT to change as it scans, producing the light and dark patterns that make up the picture on the tube's phosphor coat.

Photograph courtesy of the Office of Educational Communications, State University of New York at Binghamton.

OBJECTIVES

The list of learning goals below should help your study of the experiments, reading material, and problems included in this module. If you are able to perform all of the tasks in this list, you should have no trouble with the test that will follow at the end of the module. You should be prepared to

1. Give the rules for attraction and repulsion of electric charges.
2. Describe the transfer of electric charge from one body to another and the effect of electric charge on metal surfaces.
3. Define electric field, electric intensity, potential difference or voltage.
4. State the names of the Standard International (SI) units for all quantities that appear in the equations of this module.
5. Use the law $F = (KQ_1Q_2)/r^2$ and the expression $F = qE$ to solve problems.
6. Discuss the properties of field lines and equipotential surfaces and tell why they intersect at right angles.
7. Determine the path of a charged particle that enters a electric field perpendicular to the field.
8. Calculate the final kinetic energy and velocity of a charged particle, given the initial velocity and the potential difference through which it moves.
9. Measure, using the apparatus of laboratory experiment 3, the deflection of an electron beam on the face of a CRT as a function of the voltage on the deflecting plates.



" I DON'T CARE ABOUT THE LAWS OF PHYSICS . I'M A PRACTICAL MAN ! "

WHAT YOU WILL STUDY

The main topic of this module is electricity. Electricity is so common in our lives that no one needs to be told how important it is. Knowing the basic ideas of electricity is a first step toward understanding how electrical things work. The main ideas you will learn here are: (1) that there are two kinds of electric charge (called positive and negative), (2) that two or more charges always exert forces on each other (you will learn how to calculate the size and direction of these forces), (3) the meaning of the term "electric field," (4) how to find the forces acting on a charged particle in an electric field, (5) the meaning of electrical potential energy, (6) the definition of kinetic energy, and (7) the importance of conservation of energy.

The electrical device you will study is the cathode ray tube (CRT). It is the main component of T.V. sets, automobile engine analysers, patient care units in hospitals, and oscilloscopes. The CRT and a few other devices (electron microscope, x-ray tube) utilize electric forces to speed up (accelerate), concentrate (focus) and deflect a stream (beam) of charged particles. Frequently, magnetic forces are used for focusing and deflecting. This is true in the case of T.V. picture tubes, particle accelerators and mass spectrographs. The physics you learn in this module can help you understand all these devices and many more.

CATHODE RAY TUBE

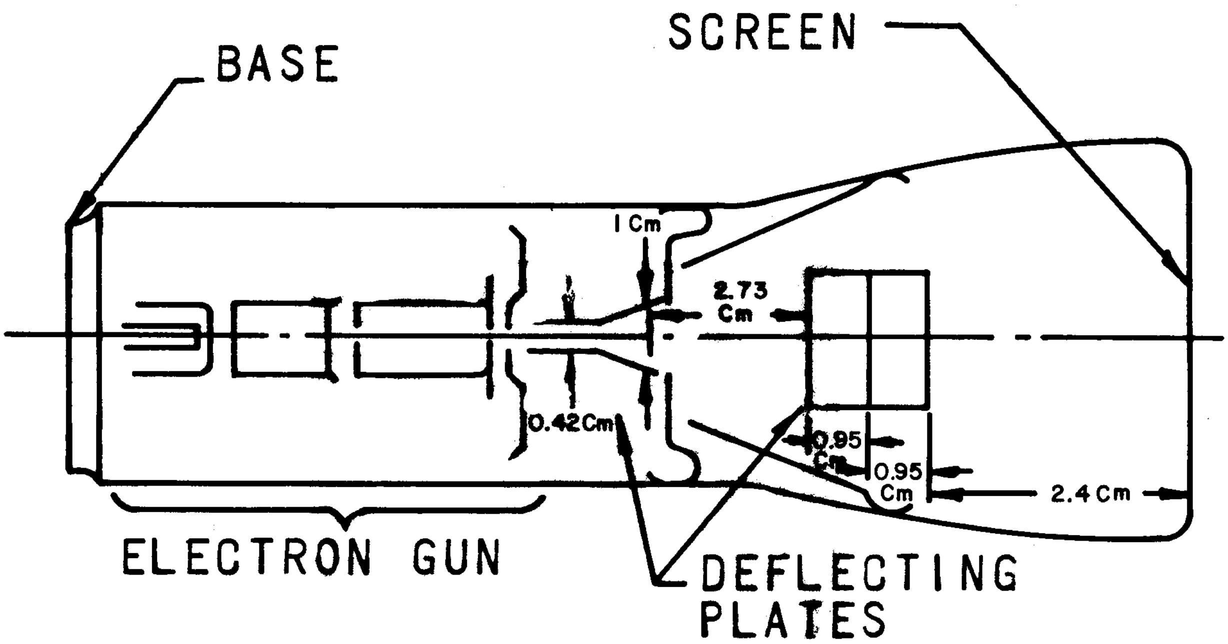
The parts of a cathode ray tube(CRT) are shown in Figure 1. They are a glass container called an envelope, an electron gun, deflecting plates, a screen, and base. The envelope holds and protects the other parts and keeps them in a vacuum. The electron gun does three things: It supplies electrons[1], accelerates them, and shapes or focuses them into a narrow beam. The deflecting plates control the path of the beam and can make it strike anywhere on the screen. The screen is a coating on the inside of the glass called a phosphor which lights up and thereby makes visible the spot where the electron beam strikes. All electrical connections are made through the base.

The black and white picture on the television screen is formed by making a properly focussed beam scan, that is, move rapidly along closely spaced horizontal lines to cover the entire screen. At the same time the brightness or intensity of the spot is varied to provide at each point on the screen the desired shade of white, black or gray. The brightness or intensity depends on the number of electrons striking the screen per second. For the light to be seen by the eye, many electrons must strike near the same point. The control knob marked "brightness" on a T.V. set and "intensity" on an oscilloscope allows you to control the number of electrons in the beam.

The free electrons for a cathode ray tube are supplied by a process called thermionic emission. In thermionic emission electrons are boiled off with heat from a piece of metal called

---

1. An electron is the smallest charged particle -- radius less than 10^{-14} meters, mass 9.11×10^{-31} kg, and negative charge 1.60×10^{-19} coulombs.


BASE
SCREEN
I Cm
2.73 Cm
0.42Cm
0.95 Cm
0.95 Cm
2.4 Cm
ELECTRON GUN
DEFLECTING PLATES

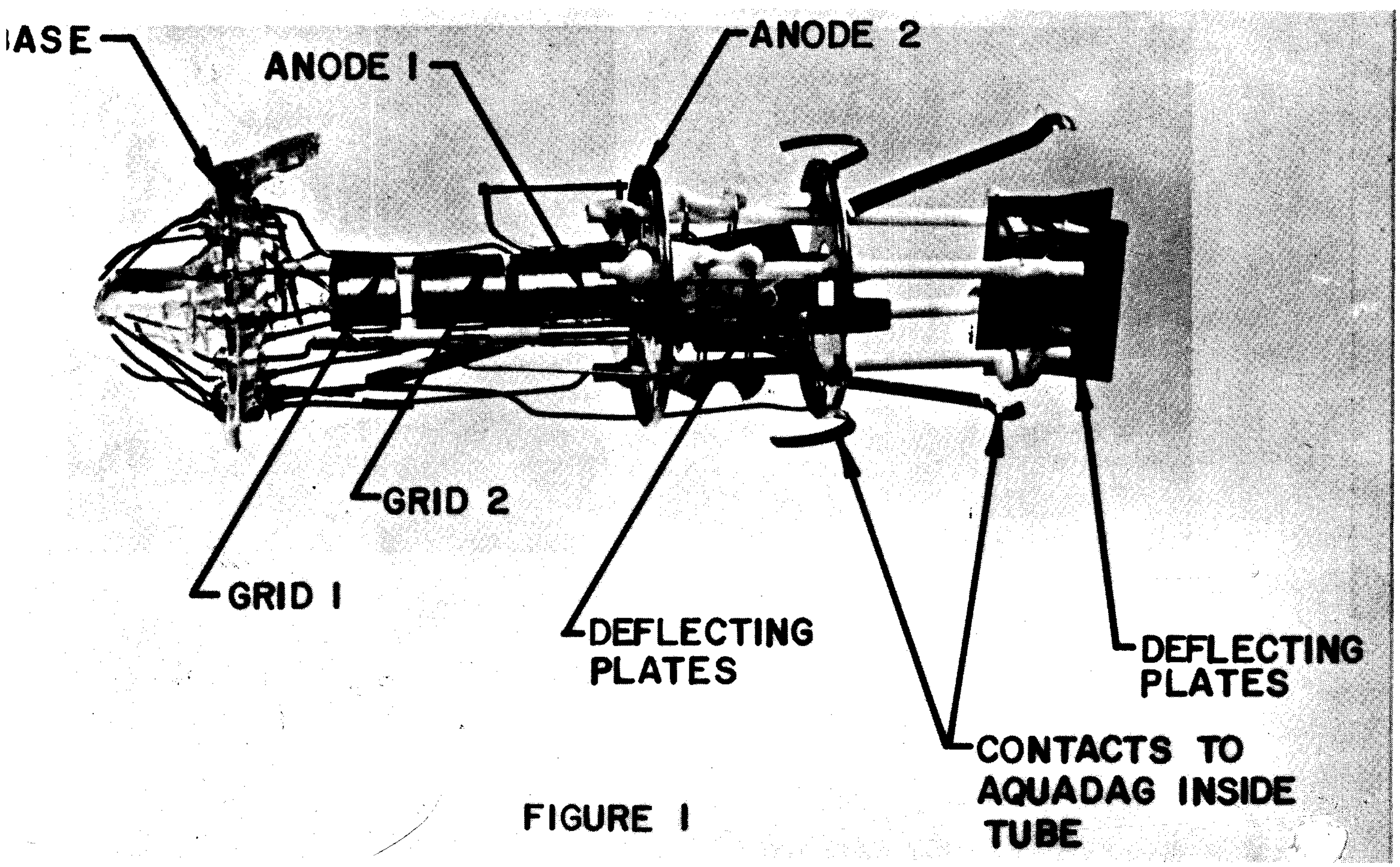

ASE
ANODE I
ANODE 2
GRID 2
GRID I
DEFLECTING PLATES
DEFLECTING PLATES
CONTACTS TO AQUADAG INSIDE TUBE

FIGURE I

the cathode. It was first observed by Edison in 1883. He noticed that a current could be made to flow from a wire that had been heated to a glowing temperature in vacuum.

Much research went into developing cathodes with long lifetimes and which could operate devices like vacuum tubes, cathode ray tubes, and X-ray tubes. The problem was that metals didn't last long at the high operating temperatures needed to get enough electrons emitted. Several solutions were found; the most commonly used one has a metal core coated with certain oxides to lower the operating temperature required for adequate thermionic emission. This type of cathode is called an oxide-coated cathode.

Modern oxide-coated cathodes often are cylindrical caps which surround a heating wire, called the filament. The filament is heated by passing a current through it and this heats the cathode.

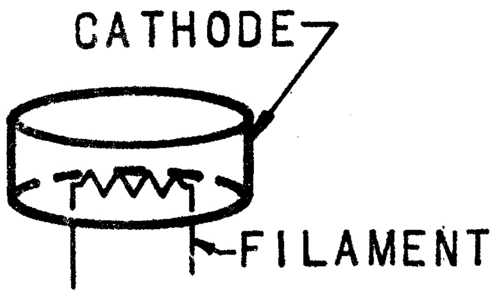
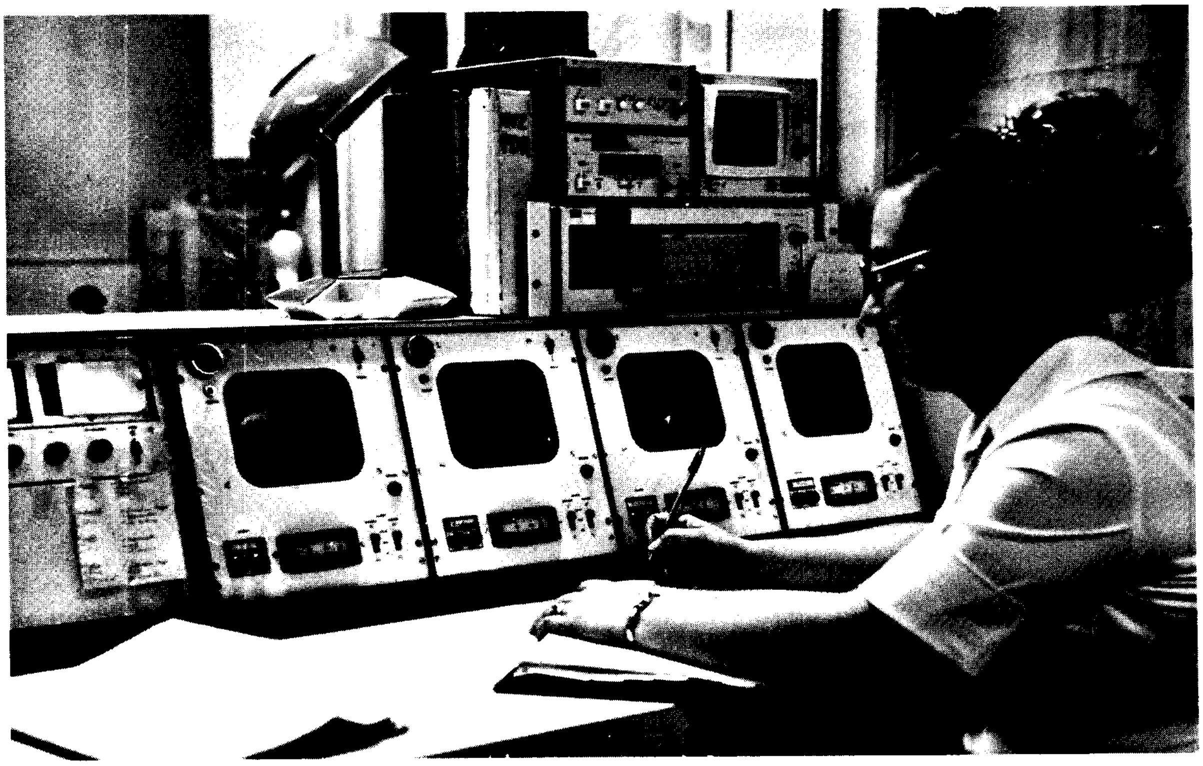


Figure 2

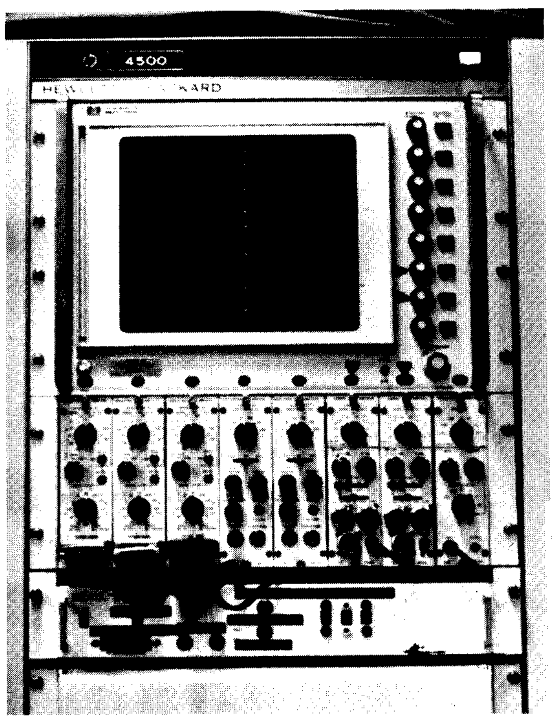
In normal operation, high voltages are applied to parts of the CRT. Care must be taken not to turn on the high voltages before the cathode has reached operating temperature, or pieces of the oxide coating may be pulled off the core. This may reduce the emission, and damage the tube.

The motion of an electron in the CRT and the electric forces which produce that motion will be the main topic of this module. Electric forces come from and act on electric charges; to understand these forces it is necessary to know something about electric charge.



Nurses can watch the electrical pulses produced by cardiac patients' hearts on the cathode ray tube monitors located in a central display panel.

A general purpose physiological monitor which displays eight traces on the large cathode ray tube. Three channels display electrocardiograph traces, two channels display heart sounds, two are for intercardiac pressure, and one is a channel for DP/DT.



Photographs courtesy of
Wilson Memorial Hospital,
Johnson City, New York

Laboratory Experiment 1

ELECTRIC CHARGE

OBJECTIVES

1. To study the effect of electric charge on a piece of metal.
2. To study the effect of electric charge on the electron beam of a cathode ray tube.

Have you ever walked across a rug and gotten a shock when you touched another person? Have you ever run a comb through your hair and noticed that the comb will pick up small pieces of paper? Have you ever noticed nylon clothing cling and sometimes crackle as you take it off? If your answer to any of these questions is yes, you have observed electric charges "doing their thing."

The purpose of this experiment is to give you a chance to see and learn for yourself some facts about electricity. Electric charges are a part of all ordinary matter. There are two kinds of charge called positive and negative. The things we use, see, and touch in our daily lives have equal numbers of positive and negative charges in them. They are said to be "neutral" or uncharged. Sometimes, when things are rubbed together a separation of charge takes place. For example, when a plastic rod is rubbed with a wool cloth, the plastic rod ends up with more negative charge and the wool cloth with more positive charge than before. They are now said to be charged -- one negatively and the other positively. Charges within neutral objects can also be separated under some conditions. Thus it is possible for negative charges in an object to move to one end of the object leaving a shortage of negative charges on the other end. This is the same as saying one end carries negative charge and the other end carries positive charge. Charge is never created or destroyed. Charges can be moved around, separated, recombined, but the net charge - that is, the total amount of positive charge minus the total amount of negative charge never changes. This is the "principle of conservation of charge."

Let's start examining the behavior of charged objects. Cut a triangular piece of aluminum foil about one-half inch on each side. Form a small loop at one end of a nylon thread. Crimp one corner of the triangle around this loop and attach the other end of the thread to a support allowing the aluminum to swing freely. Handle the string as little as possible; moisture from your hands may spoil the results. If you want to remove charge from the aluminum, simply touch it with your finger. This has the effect of "grounding" the aluminum.

Follow the sequence of experiments described in the next section keeping a written record of what you did and what you saw.

PROCEDURE

1. Begin by rubbing the hard-rubber rod with a piece of Saran wrap. Hold the rod near the suspended aluminum foil without touching.
2. Hold the piece of Saran wrap near the foil without touching.
3. Touch the foil with the rod.
4. Remove the rod and hold the Saran wrap near the foil.
5. Touch the foil with the rod, then touch the foil with a

finger. Now approach the foil with the rod.

6. Try similar experiments using other charged materials (glass rod rubbed with silk cloth; rubber rod rubbed with cat's fur).

7. Find out whether electrically charged rods have any effect on the electron beam of a cathode ray tube.

   To do this, you may use a ready-made oscilloscope if one is available, or the cathode ray tube that is provided with this module and wire it as shown in Figures 3 and 4.

   If you use an oscilloscope let your instructor advise you how to operate it. If you use the CRT of the module, start with the DC switch on STANDBY. Turn the AC power switch to ON and observe the red glow of the filament behind the cathode. <u>Wait at least half a minute</u> before turning the DC switch, which controls the high voltages, to ON. Focus the beam by adjusting the B and C voltages on the power supply. If the bright spot doesn't appear on the screen, try touching the B+ terminal with the brown antenna leads (Caution: High Voltage).

   (a) Is there any effect on the electron beam when you move a charged rod near the face of the CRT?

   (b) when you move it near or allow it to touch one of the deflection plate terminals?

   (c) Does it make a difference whether the charged rod is moved toward or away from a given deflection plate terminal? Note the direction in each case. Is the deflection permanent or pulse-like?

   (d) Connect a $22\frac{1}{2}$ volt battery to one pair of deflection plates. Is the deflection permanent?

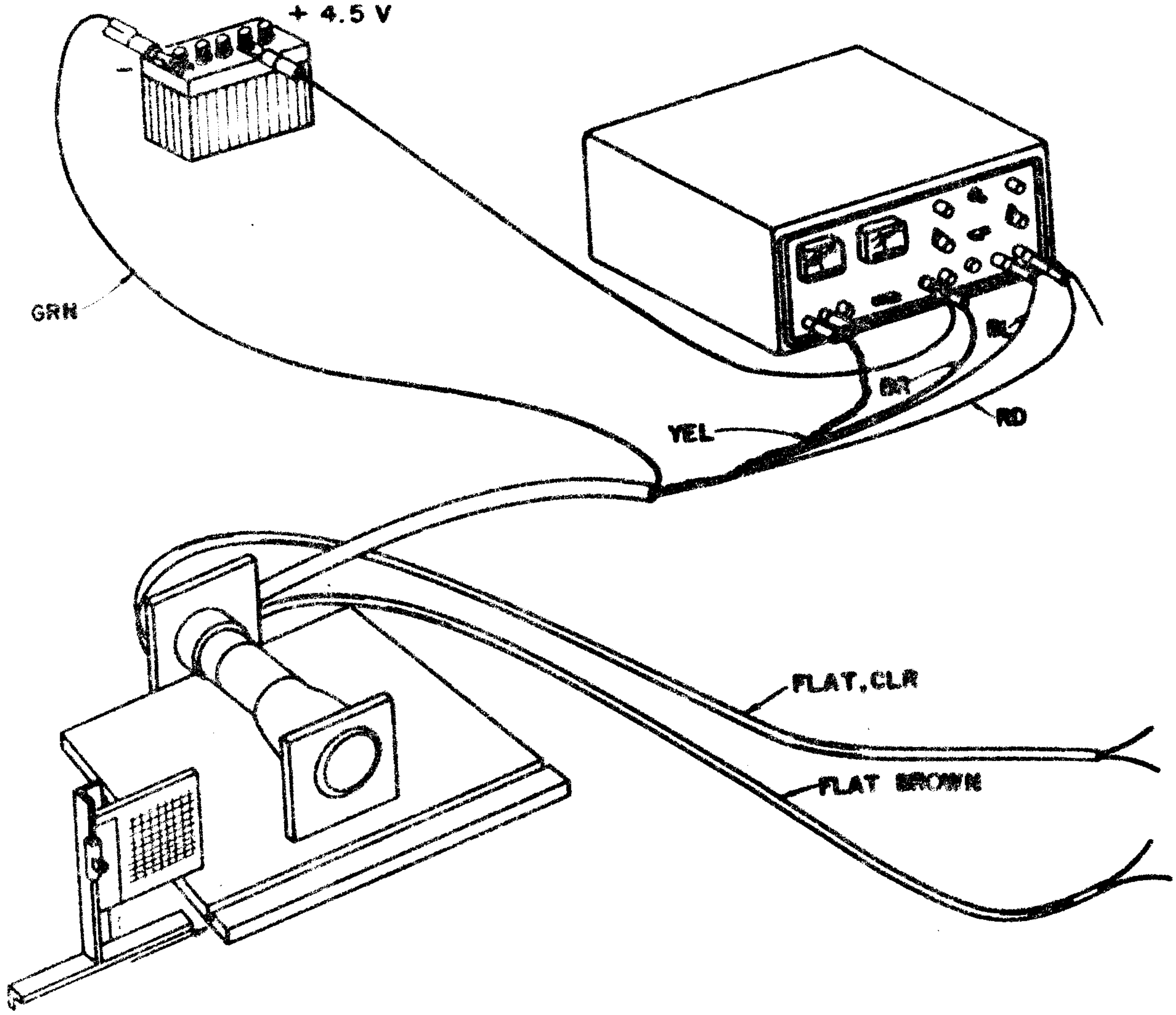

+ 4.5 V
GRN
YEL
BR
BL
RD
FLAT, CLR
FLAT BROWN

FIG.

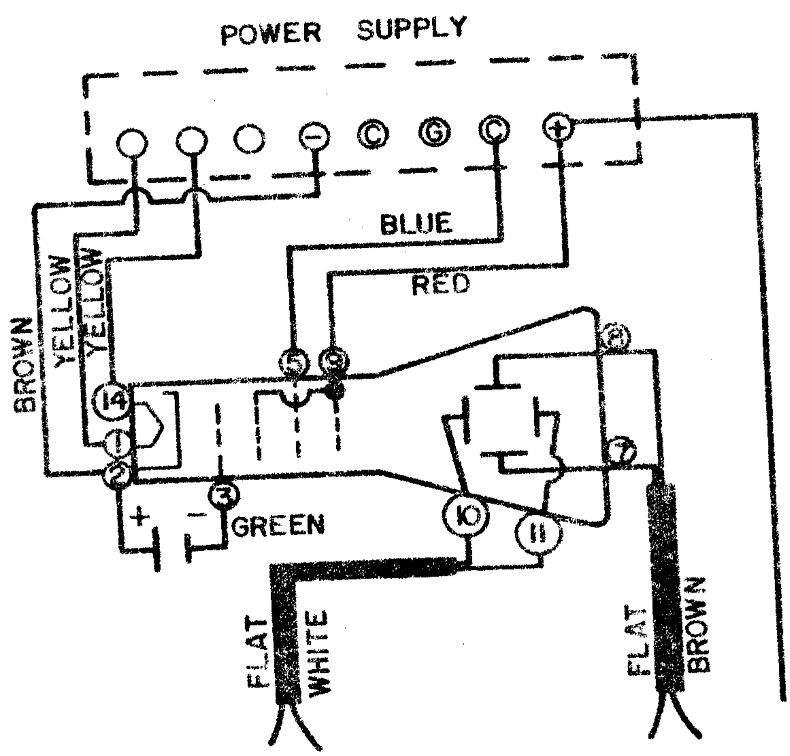

POWER SUPPLY
BLUE
RED
BROWN
YELLOW
YELLOW
GREEN
FLAT
WHITE
FLAT
BROWN

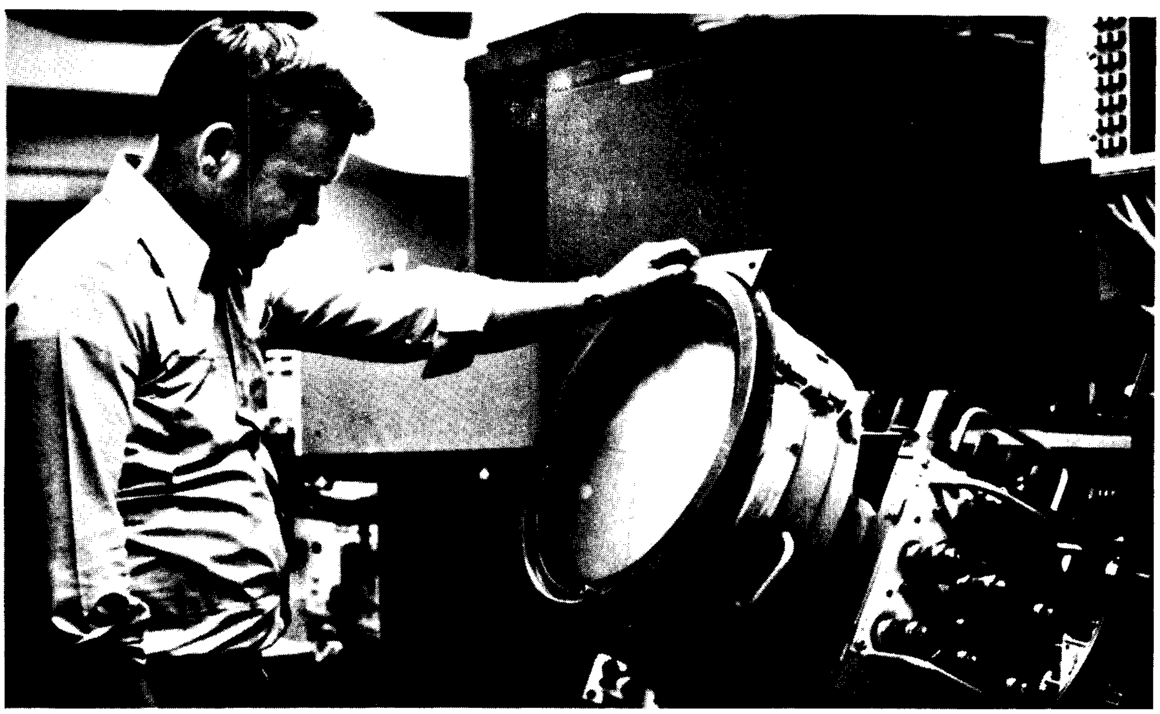
FIG. 4

(e) Do you think it is possible to determine what type of charge (+ or -) is on a charged rod by comparing the directions of deflection which you observe for the rod and the battery? Plan your own experiment.

QUESTIONS

1. Why should you ground (by touching) the aluminum before each new observation?
2. Which of the things that you tried show that like charges repel and unlike attract? Explain how each shows it.
3. What difference, if any, did you see in the behavior of the foil when held near a charged rod before and after being touched with the rod? Explain in terms of charge.
4. What effect does touching the foil with your hand have? Explain, using the idea of charge.
5. What happens to the charge on the foil if the string is moist?
6. Will charge stay on the foil forever if the foil is not touched?
7. What is the Principle of Conservation of Charge? What did you see that agrees or disagrees with this principle?
8. When a charged rod is moved rapidly toward a deflection plate terminal of the CRT and then pulled back, the electron beam is seen to deflect in opposite directions. Can you explain why?
9. It is known that if rubber is rubbed with cat's fur, the rubber becomes negatively charged and the fur becomes positively charged. In the case of glass rubbed with silk, the glass takes on positive charge and the silk negative charge. Do your experimental results agree with these facts?

The signals from the radar scanner are displayed on this cathode ray tube in the Broome County Airport control tower.



This picture of an older radar display tube, formerly used in the radar room of the Broome County Airport, shows the cathode ray tube and some of the electronics associated with a radar display system.

Photographs courtesy of Federal Aviation Administration and

Broome County Airport.

COULOMB'S LAW

A Frenchman named Coulomb measured the force between two small charged spheres. Coulomb found that the force depends on (1) the amount of charge on each sphere, and (2) the distance between them. Keeping the distance between the charges the same, Coulomb found that if the amount of either one of the charges is doubled, the force is doubled; if tripled, the force is tripled. In general, if either charge is made N times as large, the force becomes N times as large.

What happens if the distance is changed and the charges are kept the same? Coulomb found that doubling the distance between the charges made the force one-quarter (1/4) of what it was. When the distance was made M times as large, the force became $1/M^2$ of what it was. The way the force changes with the charge strength and distance is called Coulomb's Law. It can be written in a formula. If F is the force, Q_1 and Q_2 the magnitudes of the charges, and r the distance between them, the formula is

$$F = \frac{KQ_1Q_2}{r^2} \tag{1}$$

K is a constant that depends on the units that are used. In the SI (Standard International) system of units

F is in newtons, abbreviation -- N

Q_1 and Q_2 are in coulombs, abbreviation -- C

r is in meters, abbreviation -- m

$K = 9.0 \times 10^9$ N m^2/C^2 (for charges in air or vacuum)

The force between two point charges acts along the line joining them. For unlike (+ and -) charges, the force is attractive, as you undoubtedly discovered for yourself.

Figure 5 -- Unlike Charges Attract

For like charges (+,+) or (-,-) the force is repulsive.

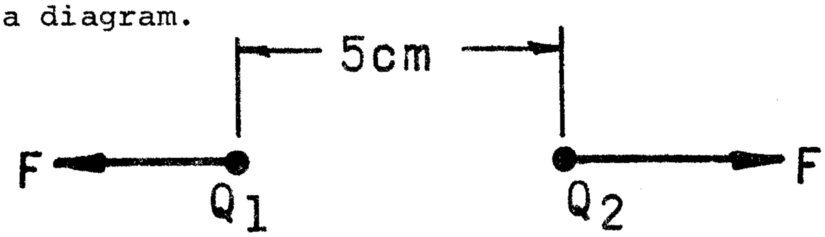
Figure 6 -- Like Charges Repel

<u>EXAMPLE</u>

Two charges are 5.0 cm apart in air. The charges are 25 and 15 microcoulombs. What is the force between them? Is it attractive or repulsive? (Note: One Coulomb is a huge amount of charge. It is more convenient to use the smaller unit:

1 microcoulomb = 10^{-6} C.)

1. Draw a diagram.



2. Write the equation to be used.

$$F = \frac{KQ_1Q_2}{r^2}$$

3. List all known and given values converting to SI units where necessary.

$$K = 9 \times 10^{9} \text{ N m}^2/\text{C}^2$$

$$Q_1 = 25 \text{ microcoulombs} = 25 \times 10^{-6} \text{ C}$$

$$Q_2 = 15 \text{ microcoulombs} = 15 \times 10^{-6} \text{ C}$$

$$r = 5 \text{ cm} = 5 \text{ cm} \times 1\text{m}/100\text{cm} = .05 \text{ m}$$

4. Put the numbers into the formula.

$$F = \frac{(9 \times 10^{9} \text{ N m}^2/\text{C}^2)(25 \times 10^{-6} \text{ C})(15 \times 10^{-6} \text{ C})}{(.050 \text{ m})^2}$$

5. State the result.

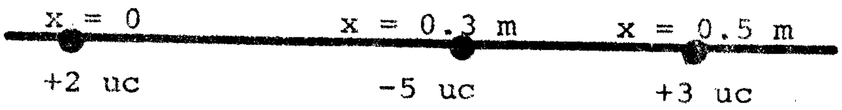
$$F = 1.35 \times 10^{3} \text{ N} \qquad \text{(repulsive force)}$$

PROBLEMS AND QUESTIONS

1. Two point charges are a distance d apart. What happens to the electric force between them if the charge on (a) one of them is doubled; (b) on both is doubled; (c) on both is tripled?
2. Calculate the force on a 40 microcoulomb positive charge exerted by a negative 50 microcoulomb charge which is 50 cm away.
3. Calculate the electric force between a proton (charge $+1.6 \times 10^{-19}$ C) and an electron (charge -1.6×10^{-19} C) which are 10^{-10} meters apart.
4. Two point charges repel each other with a force of 1.6×10^{-4} newtons when they are 1.0 meters apart. Which of the following is certainly true? The charges are (1) both negative; (2) both positive; (3) unlike; (4) like.

5. If the distance between the two charges in question 4 is increased to 4.0 meters, does the force between the charges, in newtons, become (1) 1.0×10^{-5}, (2) 6.4×10^{-4}, (3) 4.0×10^{-5}, (4) 8.0×10^{-5} ?

6. Three charges are placed along a straight line as shown:



(a) What is the magnitude and direction of the force on the +2 microcoulombs charge?

(b) What is the magnitude and direction of the force on the negative charge?

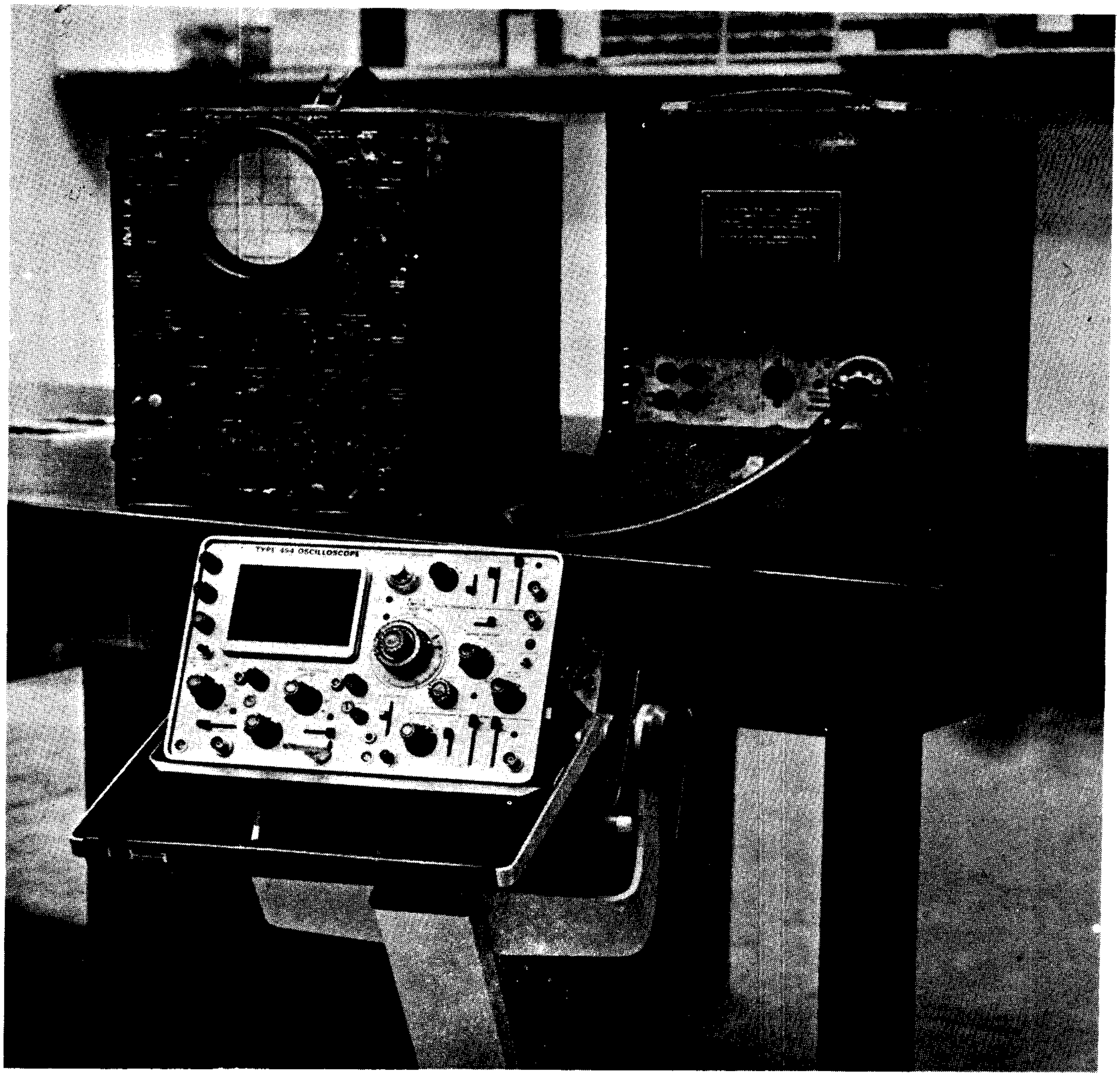
[Hint: To do this problem, you must know the experimental fact that the force one charge exerts on a second charge is not changed by the presence of a third charge. (Though, of course, the third charge also exerts a force on the second charge.)]

7. Three charges are placed on a plane in the following way: (1) a positive charge of magnitude 2 microcoulombs is placed at $x = 0$, $y = 0$; (2) a negative charge of magnitude 5 microcoulombs is placed at $x = 3$ meters, $y = 0$; (3) a positive charge of magnitude 3 microcoulombs is placed at $x = 0$, $y = 2$ meters.

(a) What is the magnitude of the force on the 2 microcoulomb charge?

(b) Is the direction of the force up and right, up and left, down and left, or down and right?

(Hint: Remember that forces are vectors.)



The cathode ray oscilloscope was the first device to utilize the cathode ray tube. The large oscilloscope shown, which has a power supply as large as itself, was built in the 1940's. The modern oscilloscope is not only more compact, but has better performance characteristics.

Photograph courtesy of the Nuclear Physics Laboratory, State University of New York at Binghamton

ELECTRIC FIELDS

Electric fields are used to accelerate, focus, and deflect the electron beam of a CRT. Magnetic fields are used for beam deflection in T.V. picture tubes and to steer charged particles in particle accelerators. Fields are important in all devices that use charged particles.

Electric fields exist because of the existence of charged particles. Each electric charge is surrounded by an electric field. To know if there is an electric field at some point, we must place a charge as a test charge at that point. If the test charge is acted on by an electric force, then an electric field exists at that point. The direction of the electric field at that point is defined as the direction of the force acting on a positive charge placed there. The size or magnitude of the electric field at that point is equal to the magnitude of the force divided by the strength of the charge. This will be easier to understand as you go on reading.

As an example, let us find the electric field which is present at a point P because of the presence of a charge +Q at a point O (see figure 7).

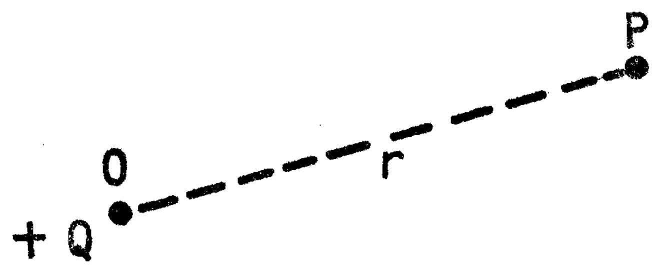


Figure 7 -- Diagram to Obtain Field of Point Charge

The distance between points O and P is r. To determine the field at P, we must put a positive electric charge there, measure the force on it and divide the force by the size of the charge. Let q be the size of the test charge put at point P. We can save ourselves the time it would take to measure the force by using Coulomb's Law (equation 1) to calculate it. (Of course, we could not do this unless Coulomb and others had taken the time to do the experiments needed to discover and verify his law.)

$$F = (K\ Q\ q)/r^2 \qquad (2)$$

If we now divide the force F by the charge q which we put at P, we get the force per unit charge

$$F/q = KQ/r^2 \qquad (3)$$

The letter E is commonly used for F/q and is called the electric intensity*.

$$E = F/q \qquad (4)$$

E is force divided by charge which in SI units is newtons/coulomb (N/C). The direction of the electric intensity is taken to be the same as the direction of the force F. The electric intensity E is a vector; it has both magnitude and direction.

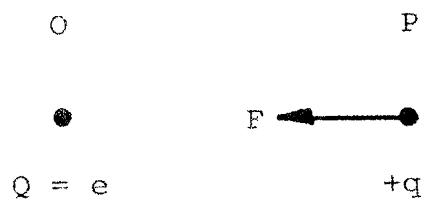
EXAMPLE

What is the electric intensity at a distance of 1 cm from an electron having charge e?

---

*Intensity (here) means field strength, and so electric intensity means electric field strength.

1. Draw a diagram.



A positive charge placed at P would be attracted to the negatively charged electron. The force F is drawn in the direction from P to O to show that attraction.

2. Write the equation to be used. The electric intensity for a point charge is given by equation (3)

$$E = KQ/r^2$$

3. List all known and given values converting to SI units where necessary.

$$K = 9.0 \times 10^{9}\ N\ m^2/C^2$$
$$Q = e = -1.6 \times 10^{-19}\ C$$
$$r = 1\ cm \times 1m/100cm = .01\ m$$

4. Enter all numbers in the equation as positive.

$$E = [(9.0 \times 10^{9}\ N\ m^2/C^2)/(.01m)^2][1.6 \times 10^{-19} C]$$

5. State the result.

$$E = 1.44 \times 10^{-5}\ N/C \quad \text{(toward the electron)}$$

PROBLEMS AND QUESTIONS

1. What is meant by electric intensity?
2. How would you determine the direction of an electric field?
3. A positive test charge of 200 microcoulombs has a force of 0.50 newtons acting on it at a certain point in an electric field. (a) Calculate the electric intensity at this point. (b) What would the force be on a test charge twice as great placed at this point?
4. The electric intensity at a certain point is 11,000 N/C. Calculate the magnitude of the force on a 3 microcoulomb charge placed at that point.
5. One model of the hydrogen atom proposes that the nucleus is a stationary, positive charge of magnitude 1.6×10^{-19}C and the electron travels around the nucleus in a circle of radius 5×10^{-11} m. What is the electric intensity at the location of the electron?
6. A positive charge of magnitude 2 microcoulombs and a negative charge of magnitude 3 microcoulombs are 4 centimeters apart. What is the magnitude and direction of the electric intensity at a point halfway between them?

Laboratory Experiment 2

MAPPING ELECTRIC FIELDS

OBJECTIVES

1. To map the electrostatic field between two parallel plates including the fringe field.
2. To map the electrostatic field for a set of flared CRT deflecting plates.
3. To map the accelerating field of a CRT.
4. To map the field inside a closed charged metallic conductor.

INTRODUCTION

Fields due to electric charges at rest are called electrostatic fields. They are pictured as field lines starting on positive charges and ending on negative charges. To map field lines we make use of equipotential surfaces. "Equi" means same or equal. Electric potential means electric potential energy per unit charge. To explain equipotential surfaces let's consider first the gravitational case which is very similar.

When you lift a heavy object and release it, the earth pulls on the object, the object accelerates, and thus it acquires kinetic energy. Before the object was released, it had the ability to acquire this kinetic energy. This ability is called gravitational potential energy and is dependent on the gravitational pull and the height or level to which the object was raised. For unit mass of any object each level has its own potential energy called gravitational potential. All points on a given level have the same potential. The levels are really layered surfaces parallel to the surface of the earth and are called gravitational equipotential surfaces. On geographical maps they appear as "contour lines."

In the electrical case, if you hold a negative charge near a stationary positive charge and release it, the negative charge will accelerate toward the positive charge, thus acquiring kinetic energy. We say the separated charges possess potential energy, and because this energy clearly results from electric forces, we call it electric potential energy. It too is dependent on position. For unit electric charge sitting in an electric field there are levels or surfaces on which the electric potential energy remains the same. The electric potential energy per unit charge is called electric potential. A surface having the same electric potential is called an electric equipotential surface. In two-dimensional mapping these surfaces appear as lines when seen edge-on.

Electric potential is measured in volts. Between two different equipotential surfaces there exists a potential difference also called voltage. This too is measured in volts.

All points on an equipotential surface are by definition at the same potential. This means that a charged particle can be moved from one point to another on an equipotential surface without changing its potential energy. Changes of potential energy and thus of potential result from work done by or against an electric force. No work is done by the field on a charged particle as it moves along an equipotential. How is this possible if work is the product of the force by the distance moved? The answer is that work = force x distance only for the component of the force in the direction of the motion. If the direction of the force and the path of the motion are at right angles, no work is done by the force. Motion along an equipotential surface must, therefore, be perpendicular to the force of the field, and so equipotential surfaces are everywhere perpendicular to the field lines.

Field lines are drawn in the direction of the field. If the field line is curved, the direction of the field at any point is the direction of the tangent drawn to the field line at that point (see figure 8). Because field lines are in the direction of the force and equipotential surfaces are perpendicular to the force, it follows that field lines and equipotential surfaces always cross at right angles.

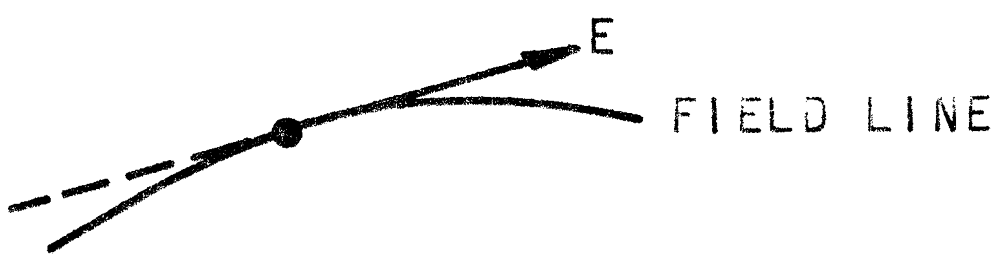


Figure 8 -- Tangent to a Field Line

PROCEDURE

1. Wire the equipment as shown in Figures 9 and 10. While some of the students are doing this, others in the group should be preparing the materials in the next step.
2. Paint the forms shown in Figures 11, 12, 13, 14 on the special teledeltos paper provided for this purpose, using silver conducting paint.
3. Mount one of the sheets of teledeltos paper prepared in step 2 on the board provided. With the negative terminal of the voltmeter connected to the negative terminal of the

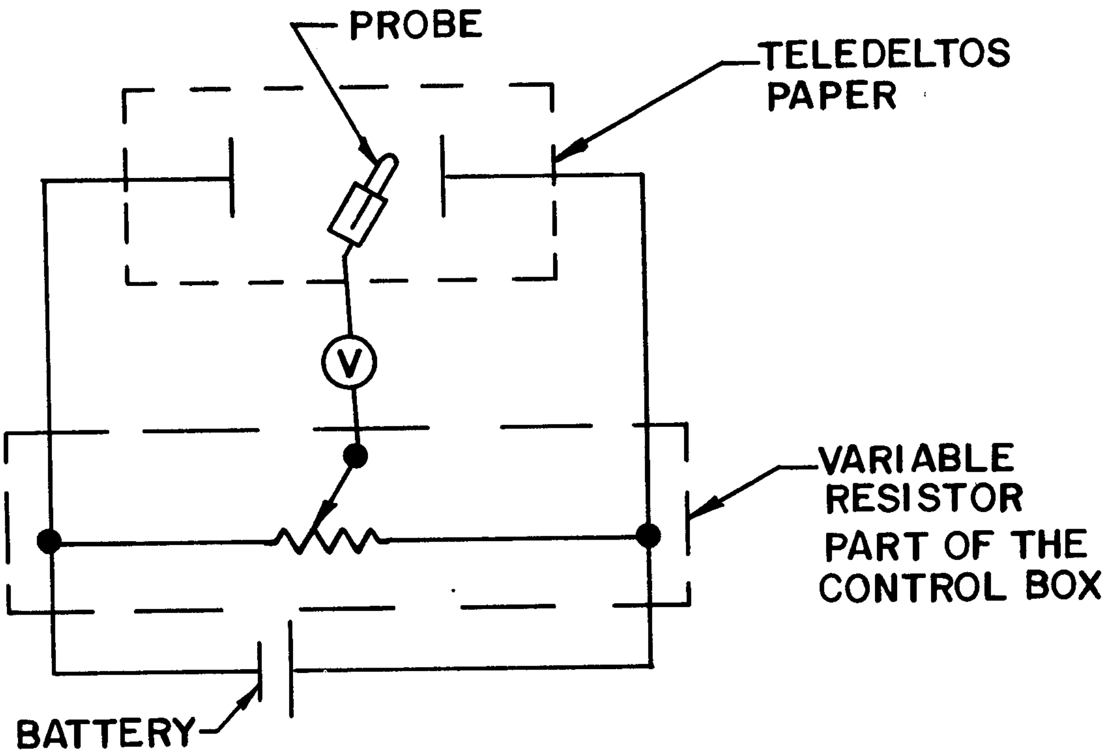


FIGURE 9

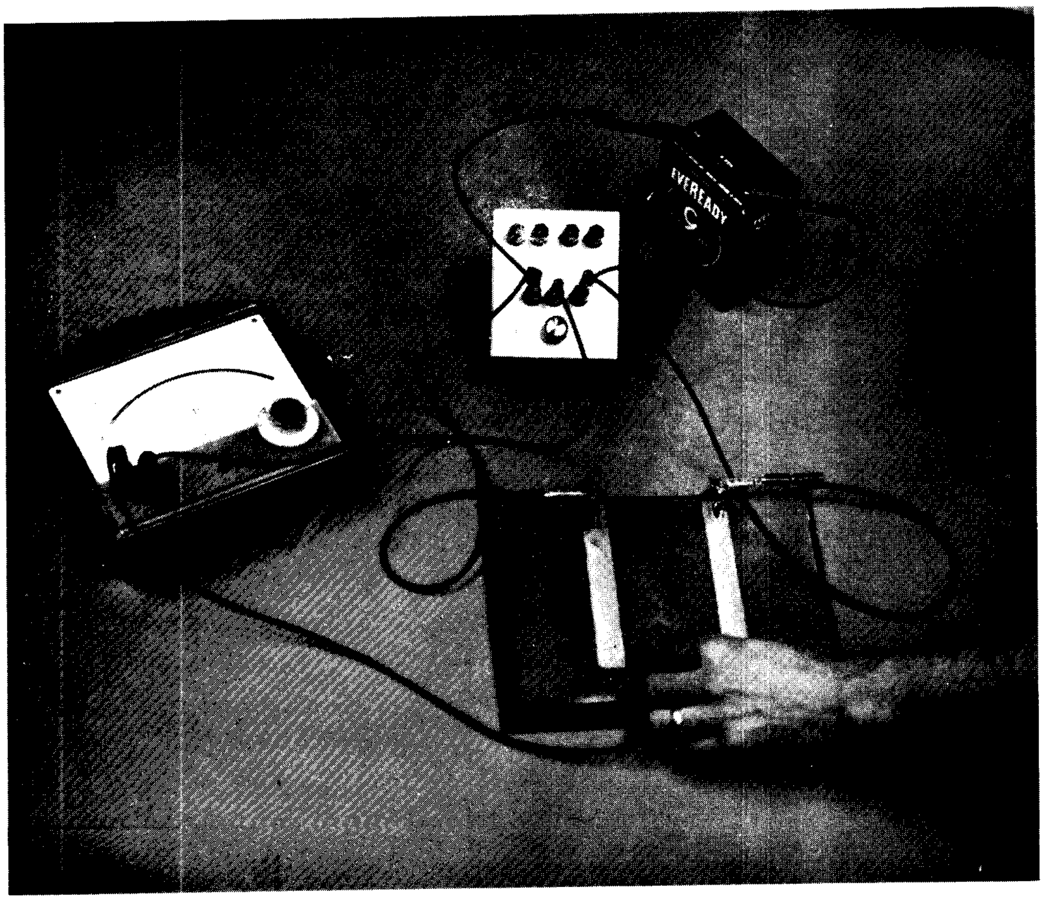


FIGURE 10

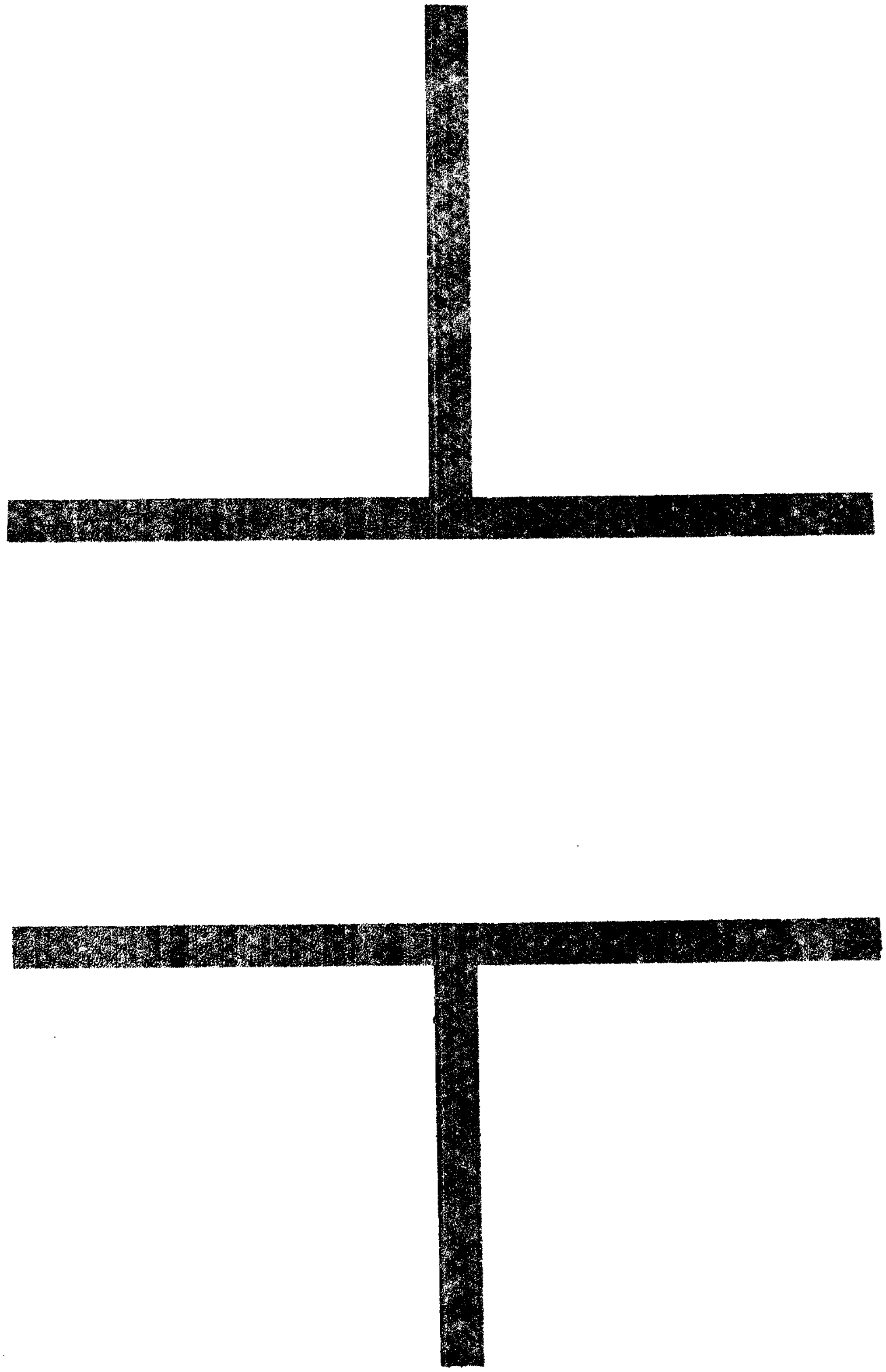


Figure 11; Parallel Plates

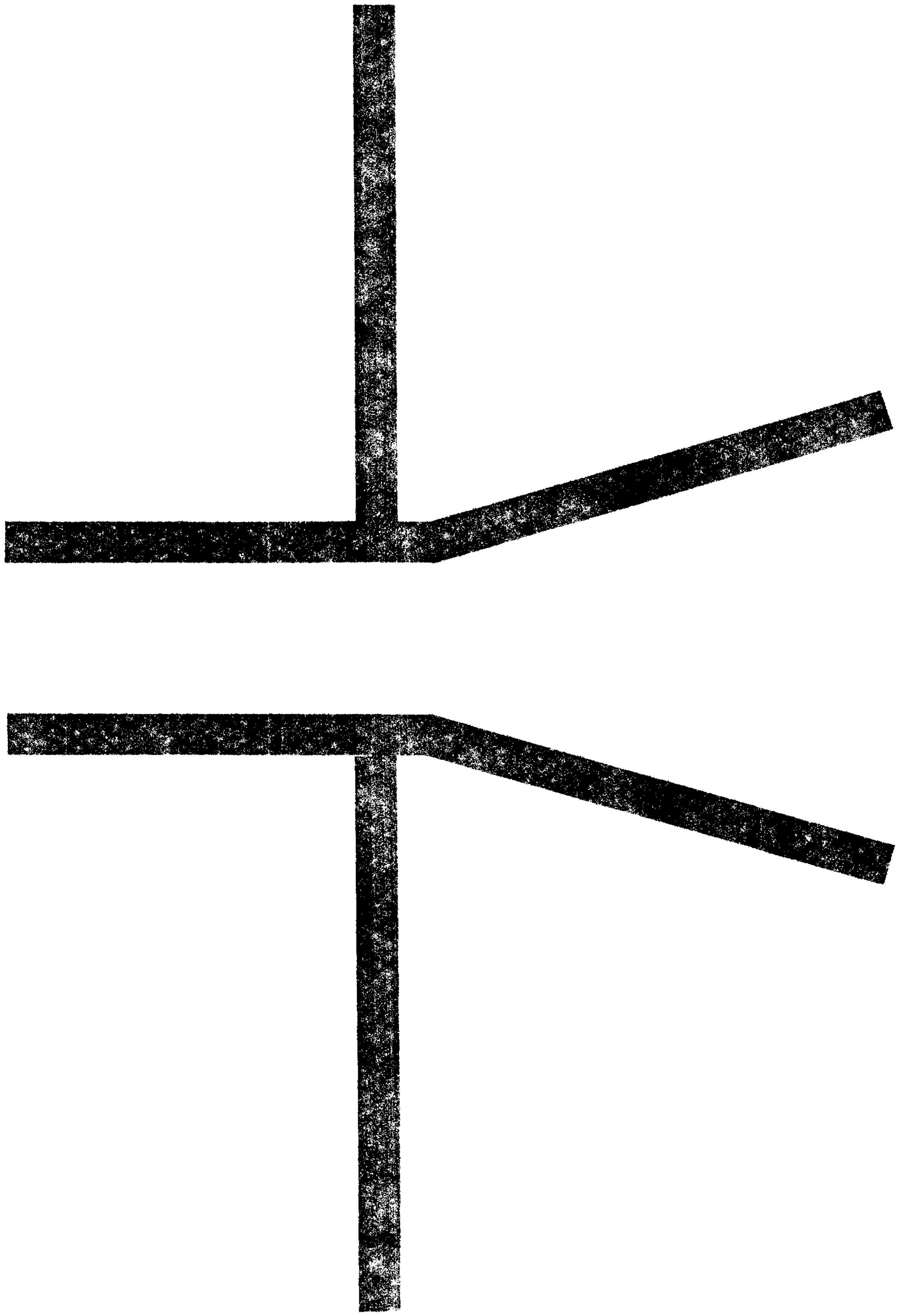


Figure 12; CRT Deflecting Plates

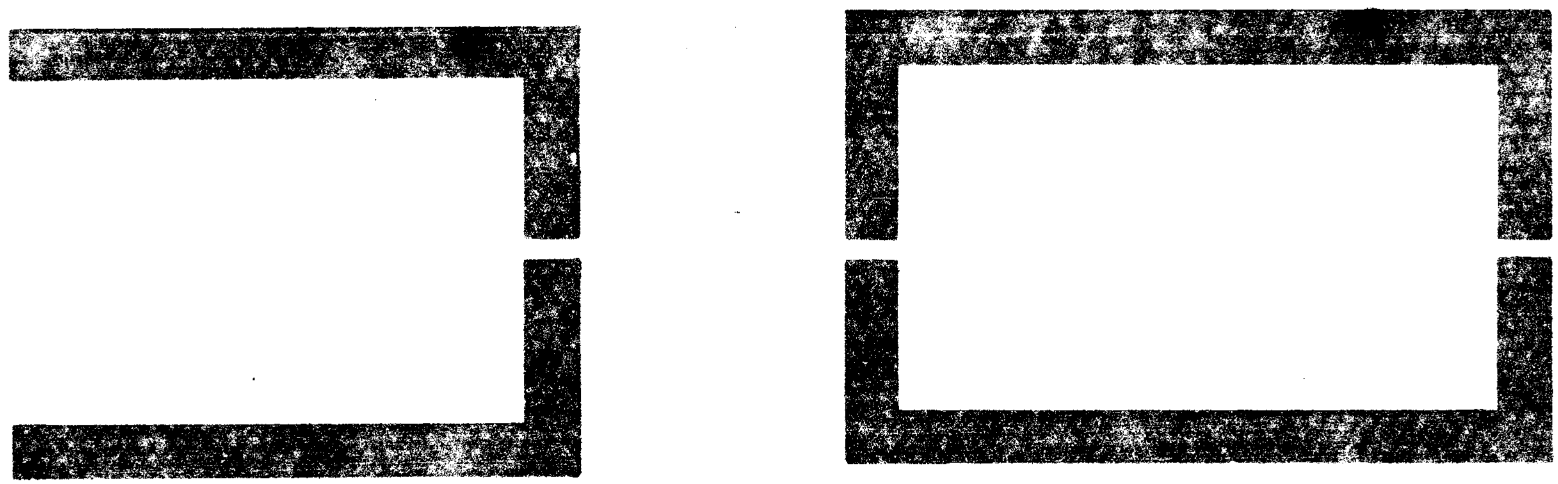


Figure 13; CRT Accelerating Electrodes

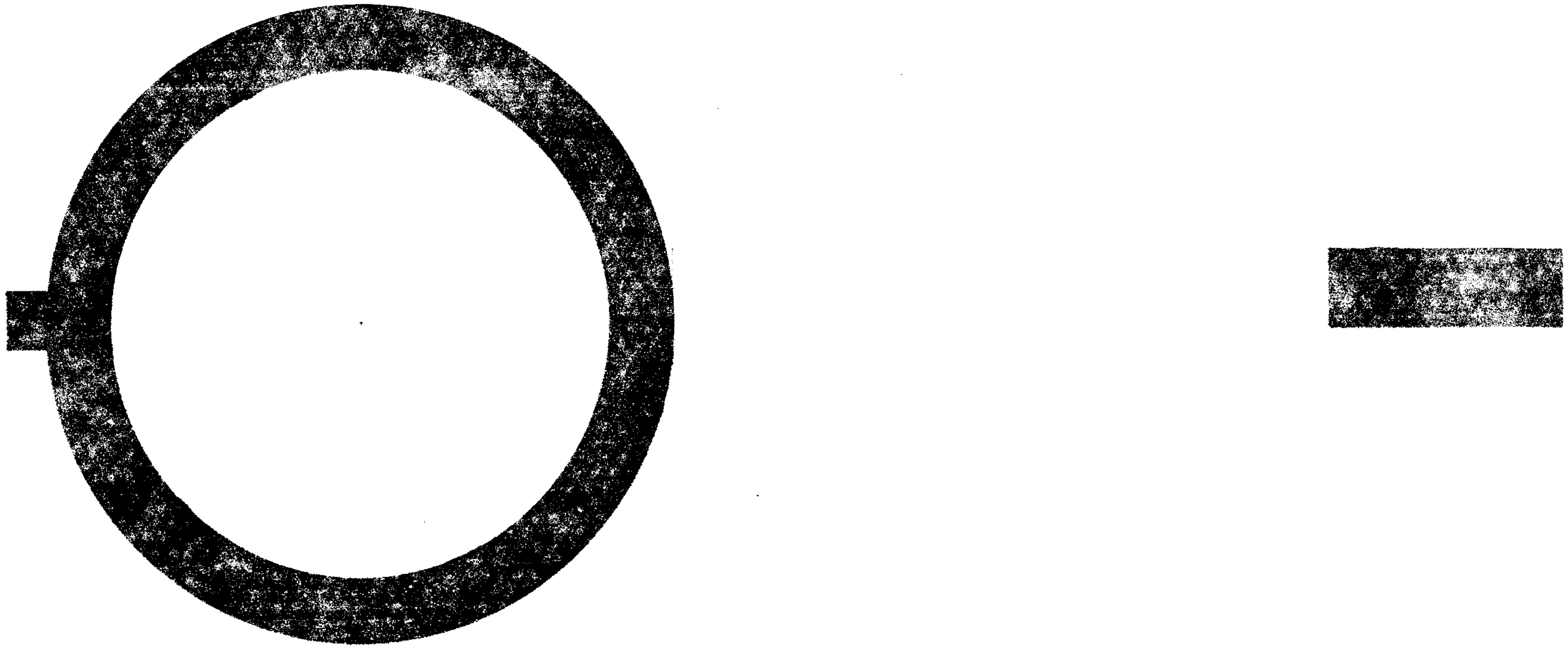


Figure 14; Closed Metallic Conductor

battery (or voltage source) and the positive terminal connected to the voltage divider, set the voltage divider for 5 volts.

4. Disconnect the voltmeter lead that is connected to the negative battery terminal. Touch this lead to the teledeltos paper. Locate the points which produce no movement of the meter needle (zero voltage). Mark these points which are all at a potential of 5 volts. Be sure to take enough points so that you can draw the path of this equipotential line between the plates and also beyond the plates. Mark the voltage of all lines on the teledeltos paper after you have finished all measurements including those for other voltages.
5. Repeat steps 3 through 6 for 10, 12, 15, 17, 20 volts.
6. Repeat the entire procedure for the other sheets of teledeltos paper.

TREATMENT OF DATA

1. Draw the equipotential surfaces as lines on all the teledeltos sheets.
2. Draw field lines perpendicular to the equipotential lines.

QUESTIONS

1. What is an equipotential surface?
2. Why is it impossible for different equipotential surfaces to cross?
3. What is a field line?
4. Why can two different field lines never cross?

5. What is the geometrical relationship of field lines to equipotential lines?
6. Are the field lines for two parallel plates parallel everywhere? How about near the ends of the plates?
7. What is the electric intensity inside a closed charged conductor? A practical application of this result is electric shielding.

CALCULATIONS

The work done by an electric field on a positive charge q in moving from a place where the potential is V_2 to a place of lower potential V_1 is

$$W = q\ (V_2 - V_1) \tag{5}$$

This is the definition or meaning of the term potential difference The particle has gone from a place where its potential energy was qV_2 to a place where it is qV_1. The decrease in potential energy is $q(V_2-V_1)$. If the particle is allowed to move freely, this decrease in potential energy will just equal the increase in kinetic energy caused by the electric force.

Select a straight field line on your field map of two parallel plate conductors. A charged particle released on a straight field line will travel along the line. Why? In traveling between one equipotential line and the next along a line of force, the work done on this particle is

$$W = F_{av}\ d \tag{6}$$

where F_{av} is the average force and d is the distance between two equipotential lines. Equations (6) and (7) are two different ways to calculate the same work. This means that

$$F_{av}\, d = q(V_2 - V_1) \tag{7}$$

Divide by d and q

$$F_{av}/q = (V_2 - V_1)/d \tag{8}$$

We recall that force divided by charge is electric intensity, so

$$F_{av}/q = E_{av} = (V_2 - V_1)/d \tag{10}$$

Start at the positive plate. Calculate E_{av} between that plate and the closest equipotential line to it on your field plot. Then calculate E_{av} between that first equipotential line and the next one. Continue until you come to the negative plate. Put your results into the following tabular form.

V_2	V_1	d	$E_{av} = (V_2 - V_1)/d$	$E = \Delta V/D$

In the formula for E in the last column above, ΔV is the voltage across the plates and D the plate spacing. This is a much used formula for calculating E between two charged parallel plates.

QUESTIONS

1. Did E_{av} remain constant or vary along the field line for which you did the calculations?

2. Are your measurements of E_{av} in good or poor agreement with E calculated from the formula $E = \Delta V/D$?

KINETIC AND POTENTIAL ENERGY

EXAMPLE

One of the fields that you mapped was that of accelerating electrodes. In the CRT which you use for this module, the accelerating voltage is about 400 volts. Calculate the velocity of an electron after acceleration through 400 volts assuming it starts with zero velocity.

The decrease in potential energy is $e\Delta V$ where e = the electron's charge and ΔV is the potential drop (here ΔV = 400 volts). This decrease of potential energy is converted to kinetic energy ($1/2\ mv^2$, where m = the electron's mass and v is its velocity after acceleration).

The kinetic energy gained by an electron in passing through a potential difference of 1 volt is equal to the loss of potential energy which is

$$e\Delta V = (1.6 \times 10^{-19}\ \mathrm{C})(1\mathrm{V})$$
$$= 1.6 \times 10^{-19}\ \mathrm{J}$$

This amount of energy is a common unit of energy in nuclear physics and is called the electron volt. The J is an abbreviation for joules, the SI unit of energy (or work).

Using 400 volts,

$$e\Delta V = 640 \times 10^{-19}\ \mathrm{J}$$

Then

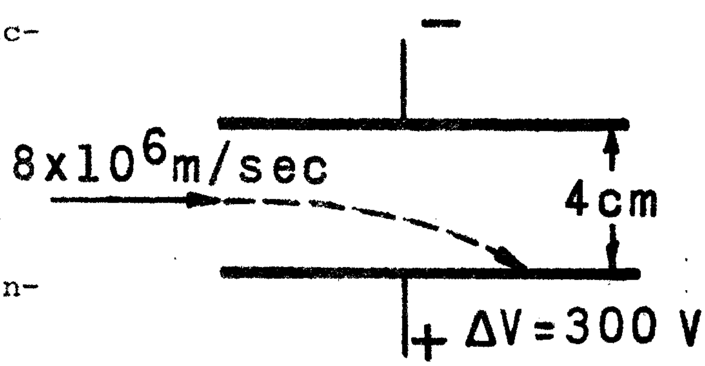
$$1/2\ mv^2 = 640 \times 10^{-19}\ \mathrm{J}$$

Solving for v gives

$$v = \sqrt{(2 \times 640 \times 10^{-19})/(9 \times 10^{-31})} = 11.9 \times 10^6\ \mathrm{m/s}$$

QUESTIONS

1. How much kinetic energy expressed in electron volts (eV) is gained by a proton that is accelerated through a potential difference of 1 volt? Answer the same question for an alpha particle. (An alpha particle has a charge equal to two proton charges.)
2. What is the velocity of (a) an electron which has a kinetic energy of one electron volt; (b) a proton which has the same energy?
3. A positively-charged particle is released at some point on the 10-volt equipotential line. Will it move toward the 8-volt or toward the 12-volt equipotential line? What is the answer for an electron?
4. Of what general principle of physics is the equation $1/2\ mv^2 = e\Delta V$ an example?
5. An electron enters the electric field between two deflecting plates midway between them with a velocity of 8×10^6 m/sec and perpendicular to the field lines as shown. What kinetic energy does it have when it hits the positively charged deflecting plate? Express this in joules and in electron volts. The electron's mass is 9×10^{-31} kg; its charge is -1.6×10^{-19} C.



[Hint: Remember that the increase in kinetic energy ($1/2\ mv^2$) is equal to the decrease in electrical potential energy ($e\Delta V$).]

6. A charged particle of mass 2 grams and charge 0.003 coulombs is falling freely under the influence of gravity with an acceleration of 9.8 m/sec^2. In the region where it is falling there is a horizontal electric field of intensity 4.9 N/C. The particle starts from rest at a point we could label with the coordinates $x = 0$, $y = 0$.

   (a) What is the path of the particle?

   (b) What is the total force on the particle?

   (c) How much work is done on the particle by the gravitational field?

   (d) How far does the particle travel in 0.5 second?

   (e) How much work is done on the particle by the electric field?

   (f) What is the kinetic energy of the particle at $t = 5$ seconds?

ELECTROSTATIC DEFLECTION IN THE CRT

Getting inside a CRT and watching the electrons move about would help one to learn how a CRT works. That, of course, is not possible. Motion pictures or strobe pictures of an electron as it moves along would be nice, but electrons are too small to photograph. However, it is possible to take pictures of their paths in cloud chambers and bubble chambers. This is similar to seeing the vapor trails of high-flying aircraft without being able to see the aircraft themselves.

Student laboratories do not have the equipment to photograph electron paths. The results of experiments are shown in Figures 15 A and B, which are drawn to scale. Figure 15A is an actual size drawing of electron paths in a CRT from the point where they enter the space between the deflecting plates to the screen. Figure 15B is a ten times magnification of the space between the deflecting plates. The sizes and spacings in Figure 15 are not the same as for the CRT you will use in the laboratory. The top set of dots that go straight across the page mark the path of an electron with no deflection. The curved set of dots show a deflected path.

Treat Figure 15 as though it were data taken by a scientist or engineer you are helping with an experiment. The objectives of the scientist are:

1. to compare the undeflected and deflected motions of an electron in a CRT;
2. to see how closely the paths can be calculated using Newton's laws when the forces acting on the electron are known;
3. to calculate how much the beam is deflected by gravity.

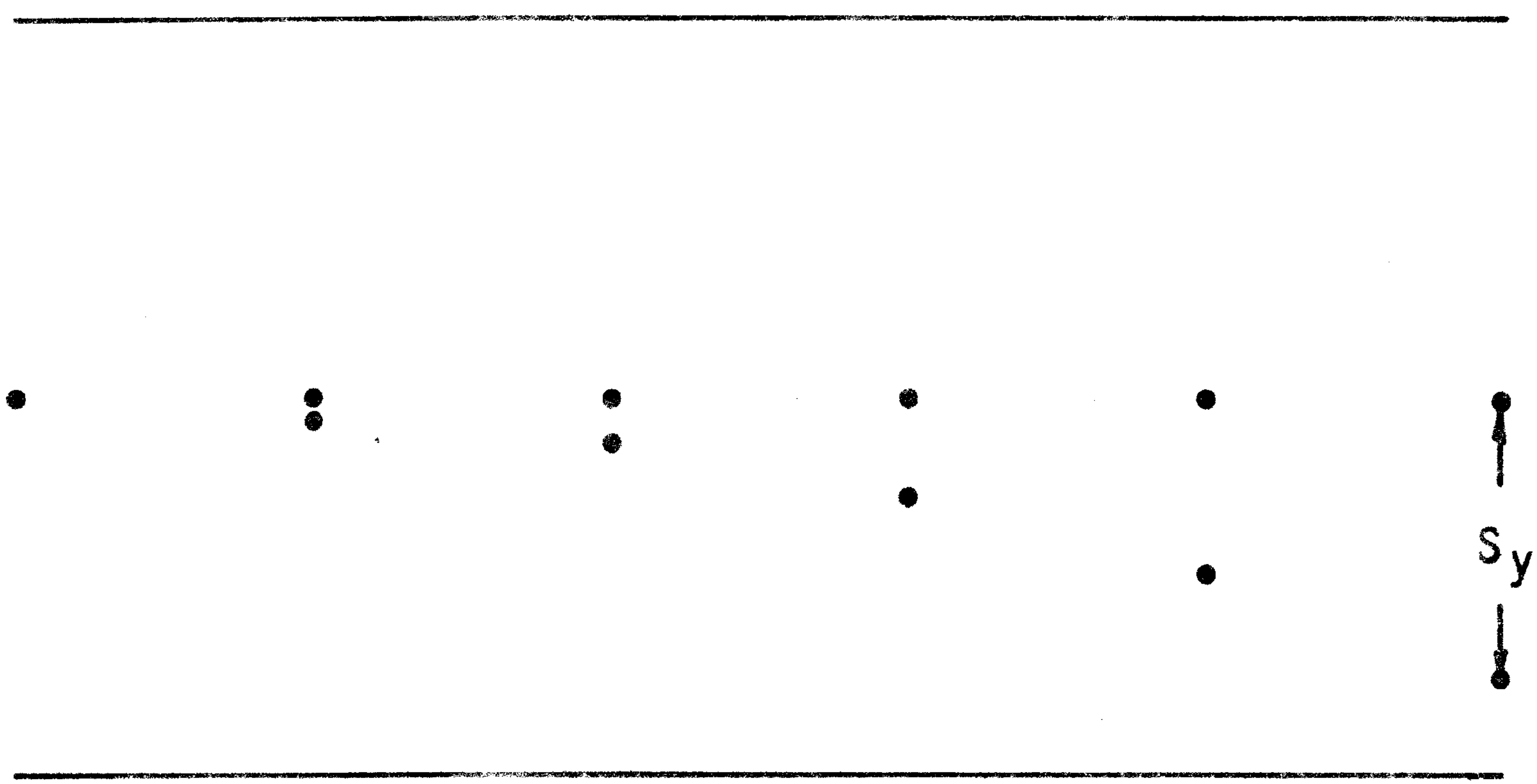


FIGURE 15 B

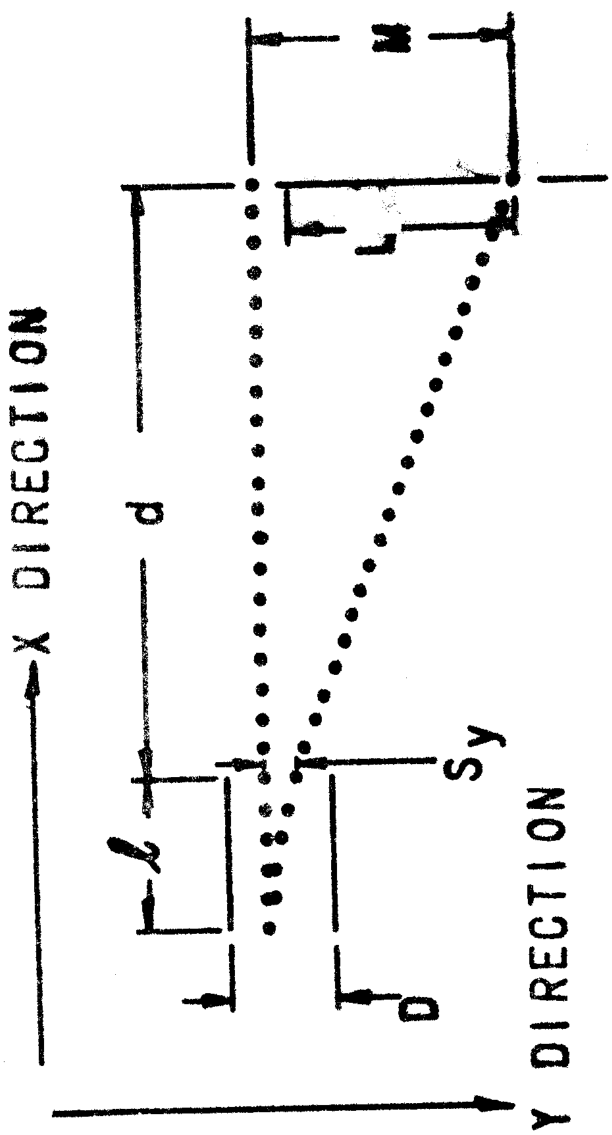


FIGURE 15 A

QUESTIONS AND PROBLEMS

The scientist tells you that the time it takes an electron to go from the place marked by one dot to the next is 4×10^{-10} seconds. He asks you to make whatever measurements (on Figure 15) and calculations you need to answer the following questions for the undeflected beam:

1. (a) What is the speed of the electron in meters/second (m/s) and in miles/hour? (1 m/s = 2.24 mi/hr.)

   (b) What voltage is required to accelerate an electron to this speed if it starts from rest? The scientist asks this question because he wants to know if the CRT is working well and accelerating electrons to the speed expected from the voltages he is using.

2. What is the length of the plates? This is marked ℓ in Figure 15A. If you were working in a laboratory, you would make this measurement on the tube. For this exercise you can make it on Figure 15A which is drawn to exact size.

3. What is the spacing of the plates? This is the distance D in Figure 15A.

4. What is the distance from plates to screen? This is the distance d in Figure 15.

5. How long a time is the electron between the plates?

6. How much time does it take the electron to travel from the plates to the screen? There are two ways to do this. Try both ways.

The scientist tells you that the curved path in Figure 15 was obtained by putting 100 volts across the deflecting plates. He asks you to see how well calculations of the deflected path based on Newton's Laws of motion agree with the experimental path in Figure 15. The next several paragraphs will help you do this.

CALCULATIONS

I Calculate E, the Electric Intensity

We know from the field mapping experiment that the field between two parallel plates is constant everywhere except near the edges of the plates. We also learned in that experiment that

$$E = \Delta V/D$$

where E is the electric intensity, ΔV is the deflection voltage and D is the distance between the plates. You have previously measured D, so E can be calculated.

You should notice that for SI units, ΔV is in volts and D in meters, and so from $E = \Delta V/d$, E is in volts/meter (V/m). When we defined field intensity by the equation $E = F/q$, force divided by charge, we said the units are newtons/coulomb (N/C). Both V/m and N/C are correct and equivalent units for E.

II Calculate the Deflection Force on the Electron

The force on a charge q in a field of intensity E is

$$F = qE$$

To calculate the force on an electron we set $q = 1.6 \times 10^{-19}$ coulombs and use the value of E calculated in step I. This force acts in the Y direction which is shown as straight down in Figure 15. This is perpendicular to the undeflected beam direction, which is the X direction in Figure 15.

III Calculate the Acceleration in the Y Direction

The acceleration in the Y direction is

$$a_y = F_y/m$$

Subscripts y are used on a and F to help us remember that the acceleration and force we calculate here are in the Y direction shown in Figure 15.

IV Calculate Velocity in Y Direction

The velocity in the Y direction at time t is

$$v_y = a_y\ t$$

This formula can be used to calculate velocities in the Y direction for the times $t = 4 \times 10^{-10}$, 8×10^{-10}, 12×10^{-10}, 16×10^{-10}, and 20×10^{-10} sec. Draw Table 2 on your calculation sheets and enter your calculated values of v_y in it.

t (sec)	v_y (m/s)	s_y (m)	s_y measured (m)
4×10^{-10}			
8×10^{-10}			
12×10^{-10}			
16×10^{-10}			
20×10^{-10}			

Table 2

V Calculate the Distance Traveled in Y Direction

To calculate the distance traveled by the electron in the Y direction while in the space between the deflecting plates, we can use the formula

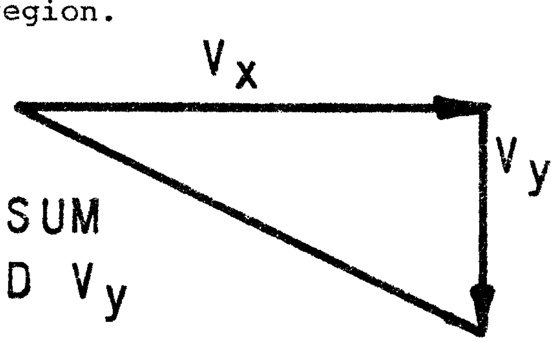
$$S_y = 1/2\ a_y t^2$$

Calculate S_y for the times in Table 2 and enter the results in your table. The values of $S_{y\ measured}$ in Table 2 are to be obtained by measuring the distances between the curved (deflected) path and the straight (undeflected) path in Figure 15.

VI <u>Calculating the Total Beam Deflection</u>

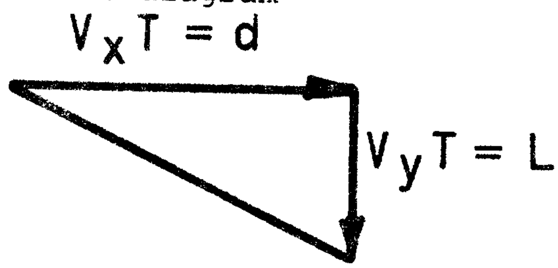
The particle travels in a straight line after leaving the electric field because there is then no force acting on it. In Figure 15, the electric field acts only between the plates. (In practice, as you found in the field mapping experiment, the field does not stop at the edges of the plates but continues more weakly beyond them.)

The electron is now in the space between the deflecting plates and the screen. It is traveling with a velocity component in the X direction given by v_x, which you determined at the beginning of this exercise. The Y component of the velocity is the value of v_y at time $t = 2 \times 10^{-9}$ in Table 2. The sum (resultant) of vectors v_x and v_y gives the velocity v of the electron in this region.



VECTOR SUM
OF V_X AND V_y

By multiplying each of these vectors by the time T that it takes the electron to travel the distance from plates to screen (d in Figure 15), we get the diagram



From $L = v_y T$ and $d = v_x T$, dividing L by d

$$L/d = (v_y T)/(v_x T) = v_y/v_x$$

or

$$L/d = v_y/v_x$$

$$L = (v_y d)/v_x$$

All the numbers on the right of this equation are known and so L can be calculated. This is the additional amount by which the electron moves in the Y direction while going from plates to screen (the distance d in Figure 15). The total distance that the spot will move on the screen is L plus the distance moved in the Y direction while the electron was in the space between the plates. This distance is S_y at $t = 20 \times 10^{-10}$ sec in Table 2.

QUESTIONS AND PROBLEMS

1. How well do S_y and $S_{y\ \text{measured}}$ compare?
2. Calculate the distance the electron will fall due to gravity as it moves between the plates, and judge whether or not the effect of gravity is significant in this case. Assume the plates are uncharged. (Gravitational acceleration $g = 9.8\ m/s^2$.)

3. An electron starts from rest in the same field as was used to calculate distances in Table 2. How far will this electron move vertically in 2×10^{-9} sec and what will its y-velocity be at that time?
4. Calculate $L + S_y$. This is the total beam deflection M on the screen. Compare your calculated value of M with that shown in Figure 15.
5. Calculate the sensitivity of the CRT. This is obtained by dividing the distance M the beam is deflected by the voltage required to produce the deflection.
6. An electron beam enters the electric field between two deflecting plates at a point midway between the plates in a direction perpendicular to the field lines. After the electrons emerge from the plates, they move in a straight line. Prove that if this straight line is extended back into the region between the plates, it passes through the midpoint of the region.

Laboratory Experiment 3

ELECTROSTATIC DEFLECTION OF THE CATHODE RAY TUBE BEAM.

OBJECTIVES

1. To produce a graph of displacement of beam spot vs. deflection voltage for both sets of deflection plates.
2. To compare observed and calculated values of deflection.
3. To compare the vertical and horizontal deflections for equal applied voltages and to explain any difference.
4. To observe and explain the effects of varying the acceleration voltage on the graphs (3).
5. To produce horizontal sweep manually and observe it.

PROCEDURE

A) Wiring

Wire the CRT as shown in Figures 16 and 17. You are already familiar with part of the circuit that was used in laboratory experiment 1. This time however, the flat antenna-type leads are connected to a voltage divider control box and to the high voltage B+ power supply.

Connect the voltmeter last. When you do, set it to a 25 volt or higher scale, connect one lead, and while watching the meter needle, momentarily touch the other lead to its point of connection in the circuit. If the needle starts to move off scale to the left, reverse the meter leads. Connect the meter into the circuit. By means of the toggle switch mounted on the side of the control box the slider of the voltage divider can be connected to either the horizontal (flat white) or vertical(flat brown) deflection plates.

WARNING: HIGH VOLTAGES ARE PRESENT IN THIS CIRCUIT
DO NOT TOUCH THE WIRING WHEN POWER SUPPLY IS ON

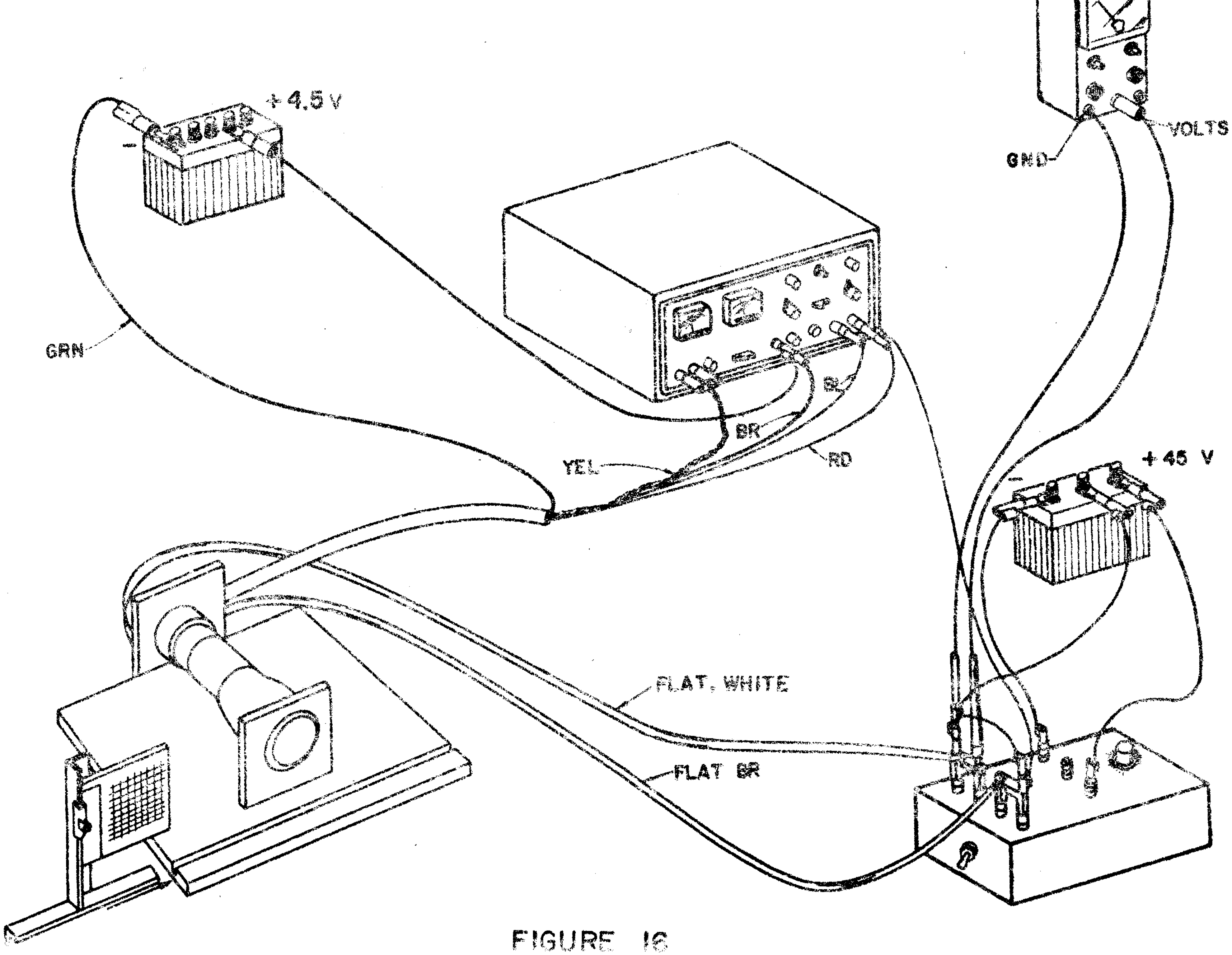
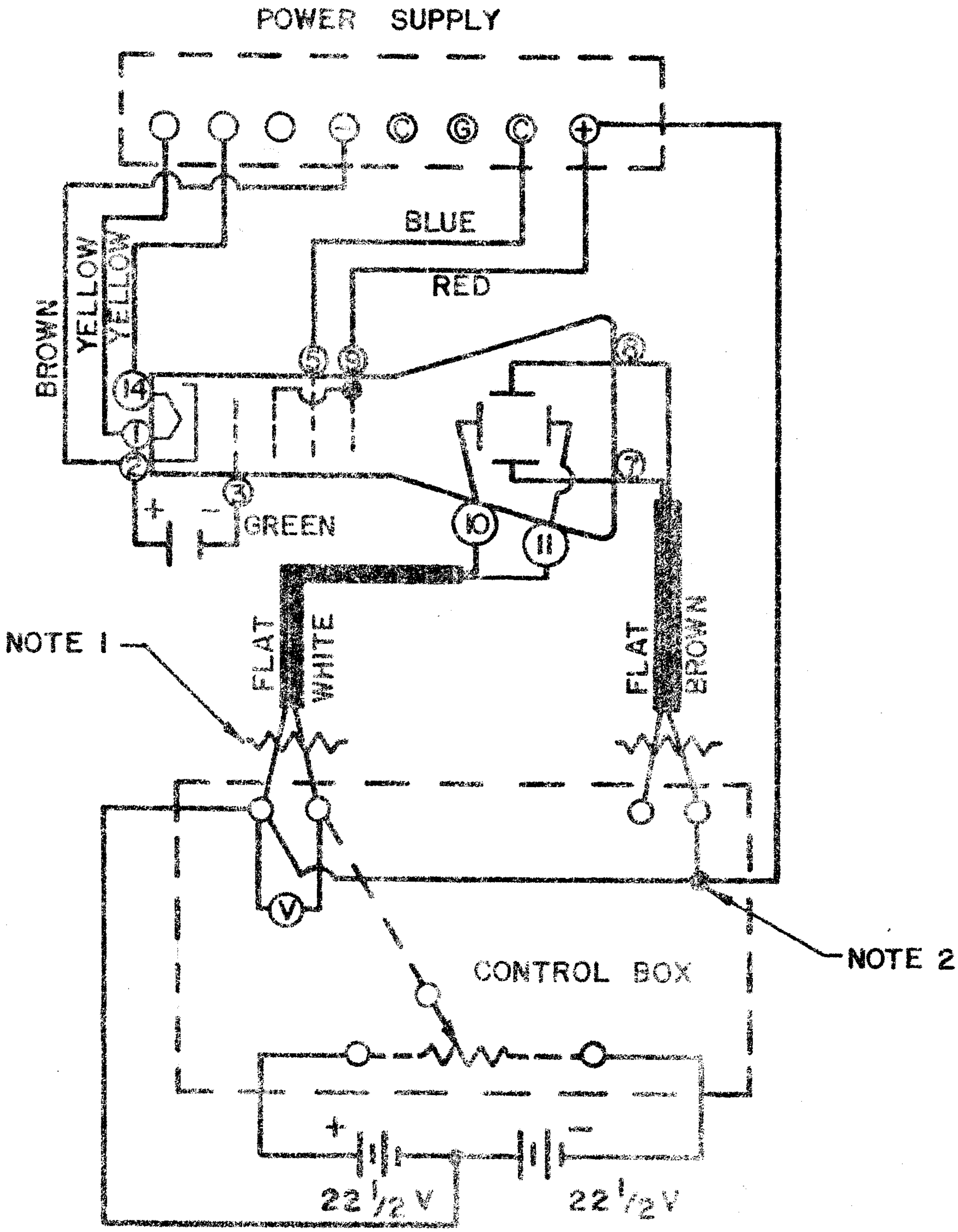


FIGURE 16



NOTES

1. 47 K-Ω RESISTORS ALREADY SOLDERED TO BANANA PLUGS.
2. ELECTRICAL CONTACT; NO ELECTRICAL CONTACT.

FIGURE 17

<u>Warning:</u> Do not touch the deflection plate terminals as you might have in experiment 1. This time they are connected to the high voltage B+ power supply and may be "hot!"

With the DC power switch on the power supply in the STANDBY position turn the AC power switch to ON. Observe the red glow of the filament behind the cathode. <u>Wait at least half a minute</u> before turning the DC switch, which controls the high voltages, to ON. Focus the beam by adjusting the B and C voltages on the power supply. The apparatus is now ready for the experiment.

If you want to know the reasons behind the wiring, here they are: The yellow wires are the filament leads. The filament is designed for 6.3 volts AC.

The brown (cathode) lead is connected to C-, the low voltage side of the C supply, and the blue (first anode) lead is connected to the high voltage of the C supply (the COMMON terminal of the power supply). The voltage between cathode and first anode can be varied between 0 and 100 volts by means of the C supply. This voltage does some focussing and acceleration of the electrons as they travel between the cathode and the first anode.

The green lead is connected to the grid which in this experiment will be kept at a fixed potential of -4.5 volts relative to the cathode. This negative potential on the grid repels electrons back toward the cathode and acts like a gate. Fast moving electrons can get past the grid and into the accelerating region between grid and first anode. Making the grid more negative allows fewer electrons to get past it; making the grid less negative has the opposite effect. In this way, the grid voltage controls intensity. The -4.5 volts used in this exercise limits the electron current to a value which will not burn a hole in the screen if the beam is stationary. It is important that the grid always be kept negative with respect to the cathode; a positive grid can result in damage to the tube.

The red (second anode) lead is connected to the B+ terminal, the high voltage side of the B supply. The COMMON terminal, to which the first anode is connected, acts as both the low voltage side of the B supply and the high voltage side of the C supply. The B supply and by means of it the voltage difference between the first and second anodes can be varied between 0 and 400 volts. This voltage accelerates and focuses the beam beyond what was done by the C supply.

The antenna type leads are connected to the deflection plates --brown for vertical and white for horizontal. Figures 16 and 17 show the wiring for horizontal deflection of the beam.

The 45-volt battery and the deflection plates are plugged into a box which serves as a voltage divider. It makes possible the application to one set of deflection plates at a time of potentials ranging from approximately -22.5 volts to +22.5 volts. The meter measures the deflection voltage.

The deflection plates are kept at the same potential as the second anode by connecting one plate of each set to the B+ terminal. This prevents unwanted charges from collecting on the plates and setting up fields that might interfere with beam focussing and deflection.

B) Checking Deflection Plate Wiring

To compare calculations and measurements, it is necessary to know which set of deflecting plates are nearer the screen. The tube manufacturer gives the information that pins 7 and 8 connect to the deflecting plates closer to the cathode and pins 10 and 11 connect to the plates closer to the screen. Which set is the horizontal and which the vertical deflection plates depends on how the tube is turned. The white flat antenna wires are connected to the plates closer to the screen (pins 10 and 11). Use these for horizontal deflections. The brown flat antenna wires are connected to pins 7 and 8. Check with a battery that a few volts applied to the white antenna lead terminals causes horizontal deflection, and applied to the brown antenna lead terminals causes vertical deflection. Rotate the tube accordingly.

C) Observations and Measurements of Beam Deflections

The movable plastic screen and plastic grids were designed to make graphing beam deflections as a function of voltage easy and quick.

Set the toggle switch on the control box for vertical deflections. Focus the beam using the largest values of B and C voltages that give a sharp focus. Record these values and do not change them until the graph is completed.

Label a plastic grid as shown in Figure 18. Mount it on the plastic screen. Set the deflection voltage to zero. The beam spot should now be near the center of the tube. Adjust the plastic screen so that the grid point for 0 deflection and 0 voltage is directly in front of the spot. Mark this point on the grid with a marker pen. Set the deflection voltage at 5 volts. Consider upward deflections as due to positive voltages and downward deflections as due to negative voltages. Move the grid horizontally, being careful not to move it vertically, so that for an upward deflection the +5 volt vertical line and for a downward deflection the -5 volt vertical line passes through the beam spot. Mark the location of the spot on the grid with the marker pen. Repeat this procedure for 10, 15, and 20 volts.

Reverse the beam direction by reducing the voltage to zero and interchanging the voltmeter leads. Proceed to plot points for meter readings of 5, 10, 15, and 20 volts.

Focus the beam for as small values of B and C voltages as possible. Record these voltages and using a marker pen with a different color ink plot a second graph on the same grid.

Set the toggle switch on the control box to give horizontal deflections of the beam. Label a plastic grid as shown in Figure 19, and mount it on the plastic slide. Now by moving the grid vertically, and taking care not to move it horizontally, a graph can be plotted for horizontal deflections in a similar manner to the one for vertical deflections. Do so for the two sets of accelerating voltages used previously. Consider deflections to the right to be caused by positive voltages and those to the left by negative voltages.

D) Horizontal Sweep

In an oscilloscope the beam can be made to move horizontally across the face of the tube at a constant speed. This is called the horizontal sweep. Try to produce this effect manually by

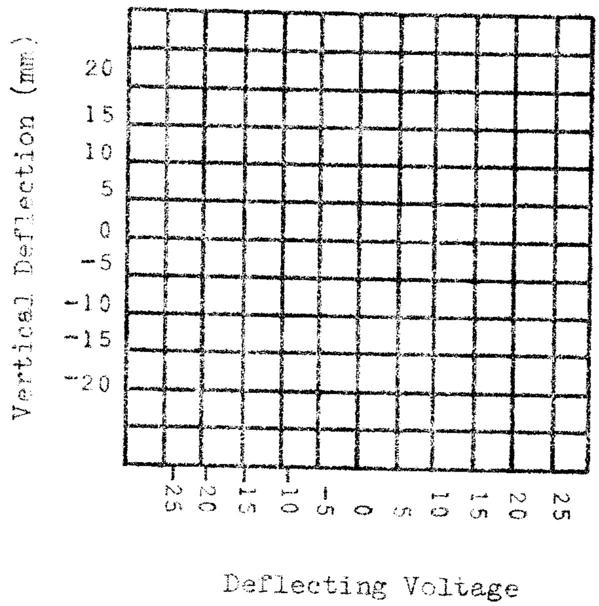


Figure 18 - Grid for Vertical Deflections

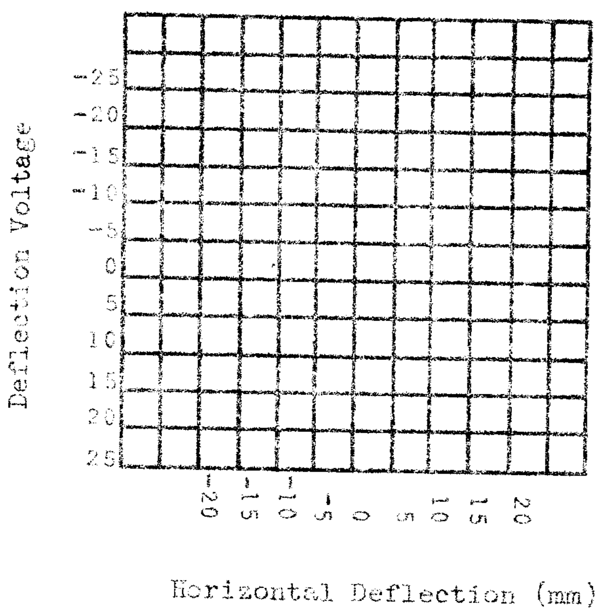


Figure 19 - Grid for Horizontal Deflection

rotating the knob on the control box, but first disconnect the voltmeter. Start the sweep at the far left of the screen, then turn the knob as rapidly and as uniformly as you can.

TREATMENT OF DATA

1. Draw a smooth line through each set of points on the plastic grids having the same values of V_b and V_c. This will produce four lines, two on each grid.
2. What is the shape of the lines obtained in step 1?
3. What effect does changing the accelerating voltage (V_b+V_c) have on the lines?
4. For the same values of V_b, V_c, and applied deflection voltage, are the horizontal and vertical deflections equal? If they are not equal, which deflections are larger?

CALCULATIONS

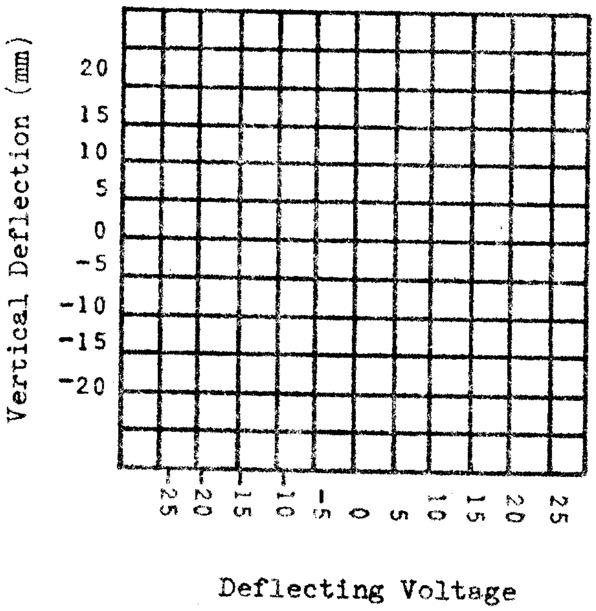
1. In a previous exercise, you helped a scientist calculate the deflection of a CRT beam. Use that method to calculate the vertical deflection for deflection voltages of +10 and +15 for the highest accelerating voltage (V_b+V_c) for which you took data in the laboratory. The dimensions of the CRT deflection system are given in Figure 1. The dimensions of the vertical and horizontal deflections plates are the same. Because the plates are flared, their effective separation is an average value which lies between 0.42 cm and 1.0 cm. It turns out to be 0.56 cm. Therefore, in your calculations assume the plates to be flat (not flared) and spaced .56 cm apart.

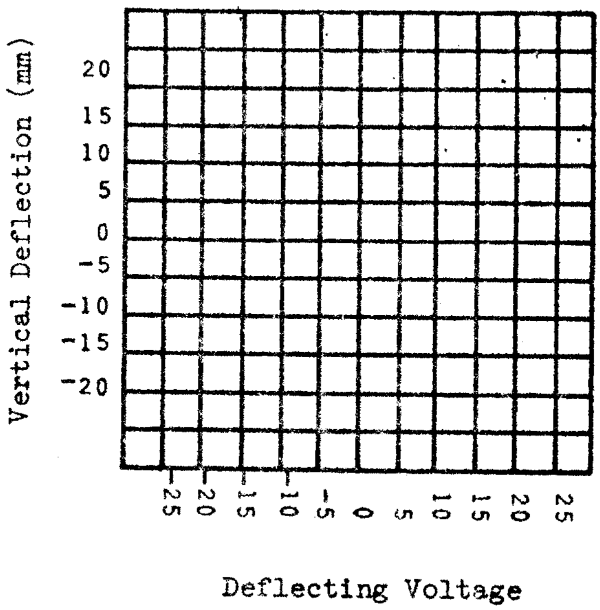
2. Perform the deflection calculation for the horizontal deflection plates using the same accelerating and deflecting voltages. You may save yourself time by noticing that only the distance from deflection plates to screen is different in the horizontal deflection as compared to the vertical deflection. Up to the point in the calculations where you use this number, everything will be the same and need not be recalculated.
3. Calculate the deflection sensitivity of each set of plates.

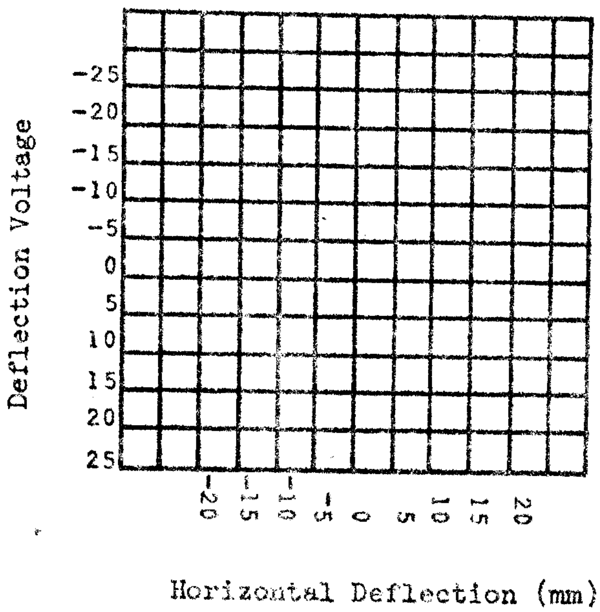
QUESTIONS

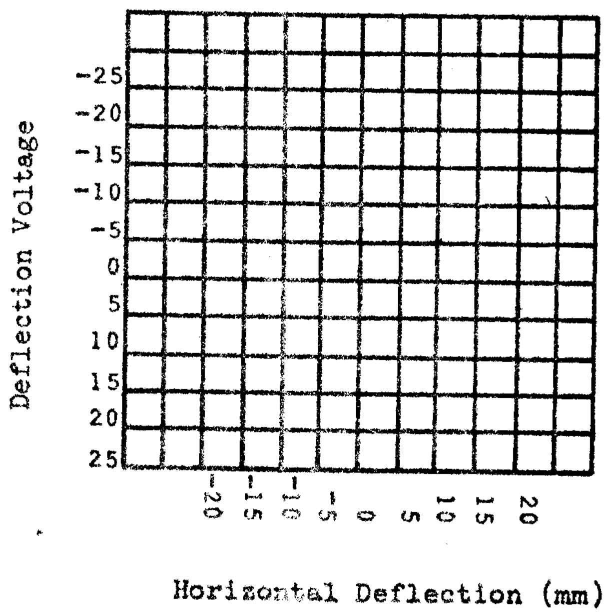
1. Does the deflection increase, decrease, or not change when the accelerating voltage ($V_b + V_c$) is decreased and nothing else is changed? Explain why this should be so. [Hint: Ask yourself the following questions. How does decreasing the accelerating voltage affect v_x? How does the change in v_x affect a_y and the time the particle is between the deflecting plates? How do these, in turn, affect the deflection S_y and the velocity v_y at the point where the particle just leaves the region between the plates? How do these and the change in time to go from deflection plates to screen change the deflection that occurs between plates and screen?]
2. How do your calculations of the deflection compare with the observed (measured) values? What assumption made in the calculations might cause differences between calculated and observed deflections?

3. When you plot the deflection of the electron beam as a function of the deflecting voltage, the points lie on a straight line. When you change the accelerating voltage, the slope of the straight line changes. If you doubled the accelerating voltage, would you expect the slope to (a) double, (b) stay the same, (c) reduce by a factor of the square root of 2, (d) reduce by a factor of 2, (e) reduce by a factor of 4?









The grids on this sheet can be used as masters for reproduction on transparencies.

PERSONS INVOLVED IN THE TECH PHYSICS PROJECT

PRODUCTION CENTERS

Florissant Valley Community College
St. Louis, Missouri

Bill G. Aldridge, Project Director
Ralph L. Barnett, Jr.
Donald R. Mowery
Gary S. Waldman
Lawrence J. Wolf
John T. Yoder
Arnold B. Arons (U. of Washington)
Steven G. Sanders (Southern Illinois University at Edwardsville)

Technical Education Research Centers
Cambridge, Massachusetts

Nathaniel Frank, Principal Investigator
Ernest Klema, Principal Investigator
John W. McWane, Project Director
Richard Lewis
Dana Roberts
Malcolm Smith
Robert Tinker

Special Training Division
Oak Ridge Associated Universities
Oak Ridge, Tennessee

Lawrence K. Akers, Project Director
John F. Yegge, Project Codirector
John Amend
Howard Dickson
Jerry Minter
Homer Wilkins

State University of New York at Binghamton
Binghamton, New York

Carl R. Stannard, Project Codirector (SUNY at Binghamton)
Bruce B.Marsh, Project Codirector (SUNY at Albany)
Arnold Benton (Am. Inst. of Physics)
Giovanni Impeduglia (Staten Island Community College)
Gabriel Kousourou (Queensboro C.C.)
John Ouderkirk (SUNY at Canton)
Arnold Strassenburg (SUNY at Stony Brook and AAPT)
L.P. Lange (Broome Community College)
Malcolm Goldberg (Westchester C.C.)

NATIONAL STEERING COMMITTEE

J. David Gavenda, Chairman
Professor of Physics and Education
University of Texas
Austin, Texas

Kenneth W. Ford
Chairman, Department of Physics
University of Massachusetts, Boston
Boston, Massachusetts

James L. Heinselman
Dean of Instruction
Los Angeles City College
Los Angeles, California

Alan Holden
Bell Telephone Labs, Retired
Box 46
New Vernon, New Jersey

George H. Kesler
Department Manager, Materials Laboratory
McDonnell Aircraft Company
St. Louis, Missouri

Theodore W. Pohrte
Instructional Development Specialist
Dallas County Community College District
Dallas, Texas

Charles S. Shoup, Jr.
Director, Corporate Research
Cabot Corporation
Billerica, Massachusetts

Louis Wertman
Coordinator, Electromechanical Program
New York City Community College
Brooklyn, New York

Address inquiries to:

Philip DiLavore, Project Coordinator
Tech Physics
Indiana State University
Terre Haute, Indiana 47809