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An Historical Overview of the Discovery of the X-Ray

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The purpose of this unit is to provide an historical aspect to the developments which lead to the discovery of the x-ray in 1895 by Professor Wilhelm Conrad Ršntgen. (This is the correct spelling, variant forms will appear in various literature.) The unit is divided into two main sections which include developments prior to that of Ršntgen in the first section and Ršntgen's work in the second section. The major focus of the unit lies in the first section of the unit which attempts to trace the connection between observations on magnetism, static electricity, current electricity, vacuum developments and the passage of electrical currents through vacuum tubes which lead Ršntgen to his discovery.

The unit could be utilized in three separate ways. First, a teacher could use the unit as a reference and teach only one of the two parts or portions of the first section. The information in this unit might then serve as a short introduction to the other units in this booklet. Secondly, the information provided which is of an historical nature and where teachers are involved in team or cluster situations, could be shared with either or both the English and history teacher. This would enable a science teacher to reinforce this information by utilizing the suggested activities. Thirdly, a science teacher could utilize both aspects of the unit entirely in the science classroom.

The unit would ideally be most suitable to students who have had or are having a course in general science or physics. The unit would be most easily understood by students who have been exposed to material on light and the electromagnetic spectrum, magnetism, and perhaps the basics of electricity. Of the topics listed, the most important would most likely be the electromagnetic spectrum and secondly, magnetism in terms of its value in understanding such concepts of field, force, attraction, etc . . . The unit could be used with students at both middle and high school levels who have had at least a minimal exposure to the afore mentioned areas.

The specific objectives in the unit include the following items:

1. To provide a vertical line of events which lead to the discovery of the x-ray.
2. To show the relationship between magnetism, electricity, vacuums, cathode rays and x-rays.
3. To provide some historical and biographic information on the men of science who contributed to developments which lead to Ršntgen's discovery.
4. To provide information on the experiments conducted on x-rays by RGntgen.

I. EVENTS LEADING TO R…NTGEN

The first portion of this unit will be presented in a linear historical line examining the contributors who worked on various aspects of physical phenomenon from the late fifteen hundreds to the late eighteen hundreds. The underlined terms should be clearly understood by the students. For this purpose a glossary of terms and definitions, as they relate to the unit, has been provided.

Dr. William Gilbert (1540-1603)

Gilbert lived in England and served as physician to Queen Elizabeth. He was a *Copernican disciple* who worked, in his spare time, on developing theories about the heavenly bodies. While Raleigh planted crops in colonial America, Shakespeare wrote in England, Galileo studied the heavens in Italy and Francis Bacon worked on his historical writings which were to lead to the formation of the Royal Society of London, Gilbert worked on his ideas.

Gilbert published his treatise *De Magnete* in 1600. It became famous in his life time. Herein he described his belief that the earth itself was a magnet which interacted with a compass needle and other magnets. He hypothesized that planetary motion might be related by a magnetic occurrence. He created a fascinating demonstration called Terella (little earth) to show his theory about the earth. It consisted of a large circular *lodestone* , which represented earth, mounted on a supporting pole so that it could be rotated freely. A small needle placed on the surface would act like a compass needle did at different places on the surface of the earth. Gilbert marked the directions in which the needle lined up, with chalk, on the lodestone and he found he formed meridian circles, similar to the lines of the earth's longitudinal lines, which converged at two opposite ends or "poles".

In his treatise Gilbert also reviewed and criticized previously written materials. One of the most popular theories which attempted to explain the causes of magnetic attraction and which might help the students to have an idea of the concept involved, was written by an ancient Roman author, Lucretius, who felt the attraction was:.

> " . . . caused in all things by a flowing out of minutest bodies. So there is from an iron an efflux of atoms into the space between the iron and the lodestone—a space emptied of air by the lodestone's seeds; and when these begin to return to the lodestone, the iron follows, the corpuscles being entangled with each other."

Gilbert did not accept the *effluvium* theory as an explanation for magnetic attraction but he thought it might be applicable to electrical attractions.

It was Gilbert who first used the term electron, from the Greek word for amber, to describe the properties of attraction which arose from friction. During his time this was the only type of electricity known. It had been known by ancient men that when *amber* was briskly rubbed it would attract light objects such as *chaff* and feathers. Amber was such a popular substance that it was carried for over two thousand years as a trade article. Gilbert's initial interest in electrical attraction had been stimulated because electrical attraction seemed to closely parallel magnetic attraction. Through a great deal of experimentation, Gilbert showed a clear distinction between electrical and magnetic occurrences.

Gilbert was the first to create a device which could detect an electrical occurrence. It consisted of a small wooden needle balanced on a pivot so as to rotate freely like the needle of a compass. He "electrified" many substances, meaning he made them behave like rubbed amber. Electrified substances would attract the needle. Gilbert described all the materials he made active by rubbing as “electrics” and those that could not be made active as “non-electrics.” He also made the observation that while lodestone only attracted iron, electrified materials would attract everything. He also observed that the attraction of lodestone for iron was not effected when the two were immersed in water while electrification was not only effected but disappeared entirely under equal conditions. He showed electrification and magnetism differed in three ways; 1) lodestone attracted iron and other magnetic bodies while electrical bodies attracted all materials, 2) magnetic attraction occurred at all times while electrical attraction occurred only when the object had been recently rubbed, and 3) electrical attraction occurred toward a central area while magnetic attraction had two areas or poles.

Gilbert’s model of electrification consisted of a theory which was similar to that of Lucretius’ magnetic theory. It consisted of the idea that the rubbed material was surrounded by an invisible effluvium which was released by the material because of the influence created by friction. He felt the effluvium extended out to other bodies and drew them in toward themselves. This theory lasted well into the eighteenth century. It was described in another way in a 1733 report of the French Academy:

> “Around an electrified body there is formed a *vortex* of exceedingly fine matter in a state of agitation, which urges towards the body such light substances as lie within the sphere of activity. The existence of this vortex is more than a mere conjective; for when an electrified body is brought close to the face it causes a sensation like that of encountering a cobweb.”

So that students will understand what a natural magnet is, obtain some magnetic iron ore, such as magnetite, from a supply house. Sprinkle some iron filings or finely cut pieces of steel wool on a piece of paper and have students observe. Have the students try to pick up heavier things made of iron such as paper clips. Students may also observe what happens if they bring the lump near a compass. Students should be instructed to observe to see if all parts of the lump attract the compass needle in the same way.

Gilbert’s Terrella may be recreated in the classroom by using a styrofoam ball or round fruit to represent the earth. This should be supported in a wooden skewer inclined at an angle to represent the earth’s axis. Insert this into a large piece of styrofoam to act as a base. Next the ball should be pierced with a magnetized knitting needle. This is created by stroking the needle along a magnet to create a bar magnet. Begin at the magnet’s center and stroke the needle toward the end several times. Turn the needle and stroke from the center to the opposite end of the magnet. (Test the results by using a compass.) Place the needle in the direction of the magnetic axis of the earth. Examine the external field around the ball using a compass.

Students might enjoy some simple static electricity experiments. However, remember in trying to conduct static electricity demonstrations weather is an important factor. On warm summer days experiments may fail since an invisible film of water clings to most materials and permits charges to escape rapidly to the ground. Best results will be obtained on a cold winter day.

Have students rub a small plastic comb with nylon, wool or fur and then dip it in sawdust or small bits of paper. Students should observe first an attraction and then a repulsion. Try to have students explain why this occurs. The charged comb may also be brought near a thin steady stream of water from a faucet. The students should observe the stream being attracted to the comb.

Students may electrify rubber balloons by rubbing with nylon, wool or fur. They can look for miniature lightening flashes in a darkened room as they bring their fingers toward the balloon. Remember that rubbed balloons will carry a negative charge while the material used to rub them will carry a positive charge.

Otto von Guericke (1602-1686)

Von Guericke, also a Copernican disciple, became interested in Gilbert's work some forty years after his death. He was burgomaster (mayor) of Magdeburg, Germany. He was a man of great influence with many friends. Von Guericke believed the heavenly bodies he observed with his Galien telescope had to be moving in empty space because, he believed, if there was air its resistance would have slowed the bodies down to a standstill. In 1646 he constructed the first air pump to create a vacuum so that he could study the effects.

Since von Guericke was politically important and quite will known it was no surprise that his experiments soon came to the attention of the King of Prussia. He created a magnificent demonstration for the king—the Magedeburg hemispheres. These were halves of heavy metal spheres which fit together in an air tight manner once the air inside them was exhausted by using his air pump. Eight horses were hitched to each hemisphere and they then attempted to pull the hemispheres apart. They were unsuccessful in their attempt. When von Guericke opened the stopcock, to allow air to enter, the hemispheres simply fell apart.

Von Guericke also contributed to the discovery of the x-ray in still another way. Beside his studies on air he created the first electrical machine using a large sulphur ball. The ball was created by melting down pieces of sulphur and pouring the fluid into a *phial* of glass. Upon cooling, the phial was broken and a perfectly smooth ball remained. He then supported the ball on an axle with a handle which could be used to rapidly rotate the ball. An assistant rotated the ball while von Guericke held a dry hand against it creating an accumulated electrical charge.

By the eighteenth century, von Guericke's machine had evolved into a large wheel with inserted lumps of amber or other material. As the wheel was rotated, the amber was electrified by passing fixed brushes of cat's fur. The generated electricity was picked up on wire brushes and lead to metallic spheres. The charge produced was considerable and early experimenters ran a great risk since a violent spark often leaped from the sphere toward the experimenter. In order to control this unwanted movement of electrical charge it was soon discovered that a second sphere, placed close to the first, connected to a large unelectrified body, such as the ground, would cause the spark to be contained without further problems. Electrostatic machines, as the generator was to be called, could produce sparks which would leap across gaps of many feet at desired times.

As a demonstration of the Magedeburg hemispheres, moisten the inside of two plumber's helpers with water and push the two ends together. Have the students try to pull the plungers apart. Explain that this particular demonstration occurs as a result of the fact that as the rubber ends approach each other the air between them is pushed away. When the rubber tries to expand a low pressure is caused between the two ends. The pressure is reduced inside while air pressure of 14.7 pounds per square inch remains on the outside holding the two ends together.

A demonstration may be performed which will show the students how to obtain many sparks from static electricity. It can be created by obtaining a piece of aluminum, approximately twenty-four centimeters square. An old aluminum cake pan will do best. Heat the bottom of the pan and place a wax candle to the center of the pan so that the wax melts and the candle sticks and acts as a handle. Unfold an old rubber inner tube from an old automobile tire and place it on the desk. Stroke its surface briskly with a piece of fur or flannel for at least an half minute. Place the aluminum on the rubber and press down hard with fingers. Remove fingers and lift the metal by the handle. By bringing a finger near the metal, a spark should be obtained. Have students try this. (Many charges may be obtained from the rubber with out repeated rubbing.) Simply have students press the metal against the rubber, press with fingers and lift the handle.

Evangelista Torricelli (1608-1647)

At about the same time von Guericke experimented in Germany, Galileo was experiencing old age and blindness in Italy. He invited a young genius, Torricelli, to Florence to be his secretary and companion. The relationship was very brief, lasting only a few month's before Galileo's death occurred. Torricelli became the successor to the Chair of Mathematics in the Academis del Cimento (Academy of Experiments). Here Torricelli pondered one of Galileo's unsolved problems—Why was it that a pump could not withdraw water higher than thirty-three feet? He postulated it was the weight of the air which forced the column of water upward. If this were so, then the atmosphere could sustain a column of mercury only one fourteenth as high since mercury is fourteen times heavier than water. He utilized a glass tube over thirty inches long and sealed at one end. His student, Vivani, filled it with mercury and placed his thumb over it. It was then inverted into a cup containing more mercury. The mercury in the tube fell until its height remained at thirty inches above the top of the mercury in the cup. Thus in the year 1643, the instrument that was later to be named the barometer was invented.

It was not the barometer that was important to the history of the x-ray but the space above the mercury since this was the first permanent vacuum ever created. The barometer would inadvertently also lead the course into further investigation due to another phenomenon which it would exhibit, described in the next section.

Students should read the selection in the packet with the slides. They should perform the experiment described there and they should complete the worksheet in the packet.

Jean Picard (1620-1682)

Picard was a French priest and astronomer most often remembered for supplying Sir Isaac Newton with the necessary calculations needed to prove gravitation as a law of the universe. However, he is also famous for making an observation thirty-five years after Torricelli as he carried his barometer up some steps one evening in the dark. He realized the dark tube had become luminous. He realized he could produce the glow again simply by agitation. He recorded his observation but it remained forgotten for some twenty years. A German professor, by the name of Bernauilli, in examining calculations of Picard's, experimented by shaking mercury tubes, with and without a vacuum, producing a light which he termed mercurial phosphorous created by the friction of the mercury on the glass. The Picard glow became the beginning of the electrical light but it was also destined to help lead to x-rays.

To give the students an idea of what Picard saw, rub a fluorescent lamp in the dark with a piece of nylon. Students will observe that a glow is created in the lamp as a result of friction. By using a charged balloon students might be able to observe sparks jump when the end of the tube is placed in contact with the balloon.

Francis Hauksbee (? -1713)

Hauksbee was curator of experiments and instrument maker to the Royal Society of London. Mercurial phosphorous was the subject of his first paper published in 1709. He utilized the air pump to exhaust bell jars and larger tubes and then inserted a few drops of mercury. Upon shaking the vessel he created a phosphorous glow as had been observed by Picard.

As Hauksbee continued his observations and devised more experimental apparatus, he mounted a nine inch diameter glass globe on a lathe-like bearing and added a wheel and a crank to turn it. He exhausted the air and revolved the globe while he placed his dry hand on it and he observed a purple glow sufficient to read large print at night. When he allowed small amounts of air to enter the tube, the glow decreased. He next replaced the globe with one which was cylindrical in nature and found he could produce not only the glow but attractional properties also. He came to notice that a quiescent vacuum tube lying near an excited one would also glow without being touched discovering *electrostatic induction* . He created bulbs within bulbs and dual rotating equipment so that each could be rotated separately in the same or opposite directions. He also produced a small friction machine which could be operated inside a vacuum tube. It was with this equipment that he first described the relationships of static electrical occurrences in exhausted vessels.

Hauksbee's scientific career seems to have lasted approximately seven years. He is not listed in encyclopedias, there is no portrait, no biography, no letters and his death is fixed approximately by the date of his last publication. However, the work he conducted opened up a whole new area.

Stephen Gray (1666-1736)

During this great period of discovery, there lived in England a pensioner of the London Charthouse, a combination monastery, boy's school and old man's home. He was old and very poor and he loved to experiment. He gathered twine, silk thread, blocks of resin, an ivory ball and other household type items which he used to create static electricity.

Between 1729 and 1736 he gave the results of many experiments which showed that the electric virtue of a tube of glass, that had been excited by friction, could be conveyed to other bodies thereby giving them the ability to attract and repel light bodies. Gray and a friend, Jean Desaguliers, conducted experiments which showed that objects such as cork, as far as eight or nine hundred feet away, could be electrified by connecting them to the glass tube with wires or hempen string. They found material such as silk would not convey electricity. They discovered distant objects could not be electrified if the transmission line made contact with earth. The line for transmission was suspended by silk threads to prevent contact with the ground. It was found that metal objects held in the hand and rubbed showed no signs of electrification. However, when mounted on a non-conductor, they became electrified. Gray realized that somehow the earth was responsible for conducting electrical charge away from the body. After this realization Gray found he could electrify any material on earth by friction. He even went as far as to suspend pupils of the house by cords and electrified them, sometimes even drawing sparks from the human body.

So Gray is credited with finding that electrical conductors must be insulated and that insulators were not conductors and that a charge could be induced in a previously non-electrified body. He established electricity as a current showing it would travel over a conductor. Gray found water to be a conductor which rendered insulators into conductors when their surfaces were wetted. This concept helps us to understand the rapid loss of charges on humid days by electrified bodies. He sent many of his papers to the Royal Society and was elected a fellow. He continued his research until upon his death bed he tried to describe to his doctor the work he still needed to complete.

Charles Dufay (1699-1739)

Dufay was a wealthy Frenchman who was highly cultured, witty, and tactful. He devoted his short life of forty-one years to the study of electrical phenomenon. He heard of Gray's work and became his rival in France. Gray's work showed casual mention of repulsion. He must have noticed that small particles which were first attracted to a glass rod were often strongly repelled after making direct contact or after the jumping of sparks on close approach. Dufay observed a scrap of gold leaf was always repelled strongly by an electrified glass tube which it had contacted. He explained this by saying the vortex of the electrical effluvium which surrounded the glass first enveloped the gold leaf and impelled it toward the tube. When the leaf contacted the tube the gold leaf acquired an "electrical virtue" of its own which would then repel the first vortex. Dufay hypothesized that gold leaf would be repelled by other electrified bodies but he found the opposite to be true. The leaf was attracted by charged *resinous* materials like amber or sealing wax. (So much modification was later found to be necessary for this theory to be correct that it soon disappeared from the literature and is considered incorrect today.)

Dufay published papers in 1733 and 1734, naming two types of electricity. Vitreous electricity was that which was produced when a glass rod was rubbed with silk while resinous electricity was produced by rubbing fur on material such as a rubber rod. (Benjamin Franklin would later use the terms positive and negative to describe two types of charge.) Today this can be summarized more clearly by stating that objects which are electrified in the same way are alike in a perceivable physical way because they have been created by identical physical actions on materials which are alike in physical nature.

And so it came to pass that electrical phenomenon passed into a period of great popularity. It was soon found that no vacuum was needed in Hauksbee globes. Hensen of Leizig found that he could substitute a pad for the dry hand, making friction and creating more efficient static machines. Electrical light demonstrations took the place of theater. Electrocution of small animals took the place of entertainment. The general population began to fill the lecture halls of colleges in hopes of witnessing the production of artificial electrical sparks. Electricity thus passed into its next generation.

Have students observe vitreous and resinous electrical charges by rubbing two glass rods or test tubes with a silk cloth and suspend one from a string so that it may swing freely. Upon bringing the other rod near, the rods will be seen to repel each other. Have students repeat, this time using two rubber rods and a piece of wool. Again the rods will repel each other. This shows that the rods must be of the same charge. If students are instructed to approach a rubber and a glass rod, the rods will be attracted to each other, indicating different charges are present.

To understand the attractive and repulsive properties of static electricity, have students conduct the following activities. First use a nylon stocking. Hold the stocking by the toe against a wall and rub the stocking at least ten times with a piece of plastic. Remove and allow it to hang freely. Watch it blossom up as if filled, allow it to cling to the wall. Point out to students that it is attracted to the wall, but it repels itself.

Students may make several different types of simple *electroscopes* to detect static charges. First students should cut two strips of newspaper approximately forty centimeters in length and about three centimeters wide. Have the students vertically rub the strips between their fingers to charge the strips. The strips will diverge. One of the strips may next be folded in the middle and hung over the edge of a wooden ruler to show the divergence when, after charging the two paper vanes, another charged body is brought near the strips.

Another simple electroscope may be created by inflating two rubber balloons and connecting them using a thin, long copper wire. The balloons should be suspended from the midpoint of the wire from a dry wooden support. Rub each balloon vigorously with a piece of wool or fur. A strong repulsion will be observed indicating like charges. The distance of separation will indicate the magnitude of the charge.

A more lasting electroscope may be created. A metal leaf electroscope may be created by inserting a large nail point downward through the hole in a one-hole rubber stopper inserted in a large flask. Attach two pieces of thin aluminum foil or other metal foil to the tip of the nail. Charges can be detected as charged objects are brought near the nail top and the foil piece diverged.

Peter von Musschenbroek (1692-1761)

In 1746 in Holland at the University of Leyden, von Musschenbroek invented what became known as the Leyden jar, or electrical condenser, in which large electrical charges could be stored which were so powerful that electrical shocks could be produced.

Brass wires were connected from a charged gun barrel to a jar which had been coated on both sides with a metallic conductor and filled with water. While Musschenbroek cranked the electrostatic machine his student held the jar and happened to touch the wire with his other hand, receiving a substantial shock. Musschenbroek almost paid with his life when the experiment was reversed and he held the jar while his student cranked, with more vigor, creating more current and a greater shock. At once he began to study the possibility of storing electrical charge in these jars. He created a demonstration in which he arranged a nine hundred foot line of monks and discharged a Leyden jar. The entire line of men hopped into the air at once letting out screams.

This new creation which would store electrical charge became standard equipment and the amount of electrification that was produced was judged visually by the intensity of the spark and bodily by the shock.

AbbE Nollet (1700-1770)

A former pupil and companion of Dufay, Nollet was not an ordained priest. He was a witty, handsome, and charming man. He was a professor in the College of Navarreat at Versailles. He traveled to Italy to investigate the experiments of Galvani and Volta. He was considered a man of genius. In 1749, he created special vacuum tubes with wires sealed in one end and he produced the Hauksbee effects by attaching conductors to his static producing machine. Nollet tubes were referred to by his contemporaries as “electrical eggs”, from which x-rays were indeed to hatch. Nollet had now assembled the necessary items needed for x-ray production—a vacuum tube and a source of high tension electricity. The addition of another sealed-in wire at the opposite end of the tube and the discovery would have been made.

If in fact Nollet did produce x-rays, he would not have known since they are invisible to the eye and it would be another ninety years before the photographic plate would be produced. The fluoroscopic screen which would be capable of translating invisible short waves into longer waves which the eye could perceive also had not been discovered.

About this time the populace began to wonder and question the value and purpose of all of this. The effect of electricity on the human body was studied in depth in hopes of finding some medical application. In other areas there came a long pause. The experimenters of the day turned backwards in time to the simple repetition of former discoveries. Little forward progress was made.

Hans Christian Oersted (1777-1851)

Oersted was a Dane who worked during this period of digestion in which many minor experimenters were assimilating electrical occurrences. After Oersted made his discovery the man, Michael Faraday, who would create a practical use for electricity and satisfy the public’s questioning would make his.

Oersted first demonstrated, in 1820, the connection between electricity and magnetism and established that year as an especially eventful one. He often demonstrated electrical effects on magnets to his classes at the University of Copenhagen and may have even made his discovery while in front of a class. He found that an electric current flowing in a wire could deflect a compass needle. When a wire carrying an electric charge was placed near and parallel to a magnetic needle it deflected it but would not if the wire was at right angles to the needle. This discovery showed a direct connection between electricity and magnetism.

Oersted went on to state electricity was not created by friction, but was an element diffused among and attracted by other matter. He stated static electricity consisted of a thing which could come and go but could never be destroyed since it existed in definite quantities which could be the subject of mathematical calculations. He also showed the power of the Leyden jar resided in the glass itself. This idea was the forerunner of Faraday's discovery that the seat of electrical actions was in the space around the conductor and this would eventually lead to the discovery of radio waves. He used the term battery to describe a series of Leyden jars joined together and he created an electrical motor which could be run for as long as one half hour on the stored electricity in the jars.

Another inventor also showed in 1829 that a spiral of copper wire through which a current was passed would attract iron acting as a magnet, and in 1824 it was found that the rotation of a copper disk, as would be used by Faraday, would produce rotation of a magnetic needle supported above it. The work of Andre Ampére in 1821 lead to the *galvanometer* which was a means of both detecting and measuring a current by means of its magnetic effects.

Students may obtain magnetism from electricity by connecting two dry cells in a series. This may be by attaching the center terminals to one wire and the outside terminals to a second wire. Connect the ends of the wires to a single knife switch. Each wire should be approximately forty centimeters in length. Hold a straight length of the copper wire horizontally and very close to the needle of a magnetic compass lying on the desk. The compass needle should be deflected when the switch is momentarily closed. Reverse the polarity of the connections to the switch to show the compass needle will be deflected in the opposite direction when the switch is closed.

If the wire is held beneath the magnetic compass this will show that the deflection direction of the needle is again reversed. Students may use a larger magnetic compass needle pivoted on a vertical axis to show the effect of the current as the wire moves about the needle.

Students may next hold the copper wire used in the first experiment vertically and move a horizontal compass needle slowly around the wire to show the needle is deflected continuously in a direction tangent to the lines of magnetic flux. By varying the distance of the compass needle from the vertical axis this may be used to show the decrease in the intensity of the magnetic field.

Next students may dip one section of the copper wire into a pile of iron filings to show the filings are attracted to the wire.

Michael Faraday (1791-1867)

At the age of nineteen, Faraday was working as an apprentice to a bookbinder when he heard a lecture given by the famous chemist who is known for his discovery of nitrous oxide, Sir Humphrey Davy. Faraday wrote to Davy and asked him for a job enclosing the notes he had taken at the lecture. Davy recognized something in Faraday and he made him his assistant in the Royal Institute.

Faraday was interested in the work of Oersted and of other scientists who were attempting to obtain continuous rotation from a magnetic needle and electric current and thus the creation of the first electric motor. Magnetism had been obtained from electricity, the next step was to obtain electricity from magnetism.

In 1831, he demonstrated an electrical current was produced in a coil of wire when a magnet was pulled out of it suddenly. Thus he discovered the relationship that relative motion between a coil and a magnet was necessary for current production. This had been difficult to observe before because the magnetic needle stayed in a steady position as long as the current in the wire remained steady. Everything visible to the eye was stationary, but it was the current, which was unseen, that was in motion. Faraday described the process of electromagnetic induction in which the force of a magnet leads to the induction of an electric current. This was a simple principle which provided the basis for the construction of *dynamos* and motors.

The dynamo he created in 1831 was made of a copper disk rotated between two poles of a horseshoe magnet. The axis and disk edge were connected to a galvanometer and as the disk rotated, the galvanometer showed a current was produced. In principle a dynamo can be composed of any suitable conductor, of many coils, which rotate in a magnetic field. The rotating conductor cuts through the lines of force in the magnetic field and an induced current is created in the coils of the rotating conductor. In each coil the induced current changes its direction during each revolution, i.e., alternates.

A device, a transformer, was used to make the current direct by reversing the current in each coil of the *armature* each time it passed a pair of conductors creating a direct current.

Besides the creation of the dynamo, Faraday contributed to the discovery of the x-ray in other ways. As early as 1819 he added a fourth state of matter to the three already known, radiant matter. Although no one had observed this matter, it seemed that changes he observed in materials going from solid to the more light, fluid states of liquids and gases showed a loss of properties and he postulated they were lost to some unseen source. He also found that the actions of an electrical current flowing through a gas followed the pattern Faraday described of a current flowing in a liquid. He felt that solutions and chemical compounds contained electrically charged atoms and he named the liquids *electrolytes* . When he applied a different *potential* to two points in an electrolyte he concluded that the negatively charged particles moved toward the positive *electrode* . He named these charged particles ions (from Greek meaning travelers)—carriers of electricity. He was also responsible for coining the terms *anode* and *cathode* .

A reading selection on Faraday will be found in the slide packet. Have students read the selection and complete the worksheet in the packet.

In his early years, Faraday performed electrolysis experiments. A simple electrolysis experiment may be conducted by connecting two wires to a flashlight battery and putting the ends into a beaker containing water and some vinegar. Students should be instructed to look for bubbles on the ends of the wires. The electric current breaks up the water into its two components, hydrogen and oxygen.

Students may build their own galvanometers by cutting a piece of cardboard as wide as a compass but long enough to fold up at the ends of each side. They should then cut a second piece in the same manner as the first, this time folding the ends down. Instruct the students to glue the two pieces together, back to back for a stand and a holder for the compass. The compass should be placed in the cradle so the north and south axis points toward the closed sides of the cardboard cradle. Next students should be told to wind one hundred turns of magnet wire (#28 or finer) over the compass and cradle over the north and south axis. Instruct students to twist the ends of the wires together to about twelve inches and scrape about one half inch of the enamel insulation off of the wire tips. When connected and current flows through the coil, it will create a magnetic field around the coil. When the coil and needle are aligned in the north-south direction, the field tends to swing the needle to the east-west direction. The magnitude of current can be ascertained by how far the needle swings.

To show how electricity is obtained from magnetism, connect two ends of a single length of approximately fifty centimeters of a large diameter copper wire to a galvanometer and move a straight section of wire quickly back and forth between the poles of a strong permanent U-shaped magnet to show that a current is produced in the wire and that the current direction depends on the direction in which the wire is moved in the magnetic field. By using two or more loops of wire in the magnetic field of the U-magnet, it can be shown that there is an increase in current as the number of loops is increased. By holding the wire stationary and moving the magnet quickly back and forth it can be shown that the current depends on the relative motion of the wire and the magnetic field.

A second way to show that electricity can be obtained from magnetism is to have students wrap one hundred turns of insulated copper wire around a cardboard tube. Instruct them to insert a bar magnet into the tube. Connect the ends of the coil to a galvanometer. Show a current is present by the galvanometer when the bar magnet is pushed into or pulled out of coil and when the magnet is held in a stationary position and the coil is moved. Have students vary the relative speed of each movement to show that the current is increased as the speed in increased.

James Clerk Maxwell (1831-1879)

Maxwell was the son of an Aristocratic family and the finished product of a university education who became inspired by the work of Faraday. While he was professor of physics at Cambridge, he became noted for his mathematical ability and his interpretation of Faraday's results in terms of higher mathematical formulas caused him to form one of the most profound theories ever created, the *Electromagnetic Theory* of Light.

In 1855 he took Faraday's descriptions of the interactions of electricity and magnetism and created mathematical equations which indicated waves similar to light in character, but not wave lengths, might exist. He postulated that certain electrical disturbances should be accompanied by the emission of *electromagnetic waves* which differed from visible light but traveled at the same speed. He inferred light was an electromagnetic phenomenon.

In 1864 in *On A Dynamic Theory of the Electromagnetic Field* , he mathematically showed his theory that electromagnetic action traveled like that of light, transverse to the direction in which the waves are propagated. He was also able to prove that the velocity of these waves is the same as light in another paper he published in 1867.

Maxwell had showed that his theory could explain all the known facts about electricity, magnetism, and light but his theories were not appealing to physicists who were not accustomed to thinking in terms of field and who could not handle the complexness of his mathematics. Maxwell's two most important predictions were that electromagnetic waves of different frequencies could exist and all would be propagated through space at the speed of light. Light itself would correspond to waves of only a small range of frequencies. Very few physicists grasped the importance of Maxwell's theoretical formulas and direct experimental results were not attained until eight years after his death and twenty-five years after his first publication on the subject.

There is a reading selection in the slide packet. Have students read the selection and complete the worksheet in the packet.

Hermann von Helmholtz (1821-1894 **)**

In Germany, the great physiologist and physicist, von Helmholtz, became fascinated with Maxwell's interpretations. He extended Maxwell's theory into his Dispersion Theory of the spectrum and he provided a space for both x-rays and radio waves, specifying their properties, which included their ability to pass through opaque materials, before either had been discovered. In essence, he was the mathematical discoverer of x-rays.

Helmholtz set his students to work. A glass maker named Muller, who later became a famous maker of x-ray tubes, was asked to supply the experimental tubes. The first of his pupils to make an electromagnetic discovery was Heinrich Hertz in 1887 (see next section). The second pupil to make an important contribution to electromagnetic phenomenon was Eugen Golstein. He studied, in 1876, the colored stream visible between the terminals in the tube as the electrical current was passed. He named it *cathode ray* . One of his later students, also one of Hertz's, Philip Lennard, would also take up the cathode ray investigations again some fifteen years later.

Heinrich Hertz (1857-1894 **)**

Hertz was the son of a lawyer and senator of Hamburg, Germany. At the age of twenty-one he entered the University of Berlin and began his studies under von Helmoltz. In 1833 he became a lecturer at the University of Kiel and devoted his time to electromagnetic occurrences and the theories of Maxwell. To prove the theory an apparatus was needed which could produce and detect electromagnetic wave frequencies other than light.

There was no way to produce an alternating current of sufficiently high frequency to cause a wire to emit a detectable electromagnetic frequency but Hertz knew that the electric spark which occurred between terminals of an *induction coil* were oscillatory, implying a motion of charge back and forth between the terminals and he recognized this oscillation as a possible means for generating electromagnetic waves. For a detector he created a receiver out of a piece of wire, which he bent into a circle, with spherical terminals which were close together. He postulated a passing current would induce an electric field and if strong enough, create a spark across the terminals. His idea worked. He could detect electromagnetic waves qualitatively by simple observation of the spark even at a distance of many feet from the induction coil. He showed the waves could be reflected by metallic conductors, focused by concave metallic mirrors and they could be detracted in passing through non-conductors. He discovered what were to be called Hertzian or radio waves.

This discovery helped to establish Maxwell's theories and the theory was then taken up by many mathematical physicists who applied the detailed analysis to a vast range of phenomenon, all with dramatic success.

Heinrich Geissler (1815-1879)

Geissler contributed to the discovery of the x-ray in two very important ways. Geissler was a skilled glass blower who lived in Bonn, Germany and was asked by experimenters during the 1850's to construct complex glass shapes. His skill in construction of scientific equipment helped him to create a second major improvement—a new form of a mercury air pump for exhausting the tubes.

Geissler used his vacuum tubes by applying high voltage currents upon the electrodes and obtaining brilliant and subtle glowing colors when he introduced various gases. The Geissler tubes were helpful to physicists and chemists in that they also helped identify characteristics of both the gases and the applied current. Absolute vacuum could not be attained because air still clung to the inner wall of the tubes, however, the degree of vacuum had been greatly improved. (The pump would later be improved even further.)

In 1857, Geissler formed a number of glass tubes in which he fused a platinum wire terminal. He applied a discharge from a Rhumkorff induction coil which had been created in 1851 by H.D. Rhumkorff. This apparatus created an even higher electromagnetic force than other devices before it, by the conductive actions of one electric circuit upon another. This resulted in even more beautiful effects being produced inside the tubes.

Julius Plucker (1801-1886)

Plucker was a professor of physics at the University of Bonn, who studied discharges in Geissler tubes. He first noted the column of luminescence in the tube was striated and next he found that diffused light at the cathode could be concentrated with the use of a magnet. This information remained constant regardless of the kind of gas in the tube.

In 1857 he published a paper and noted that particles of these could be deflected by a magnet which in turn also moved the phosphorescence of a spot produced on the glass. Thus he was describing properties of the still unnamed cathode rays.

Johann Wilhelm Hittorf (1824-1914)

Hittorf was a former pupil of Plucker who made some interesting observations in 1869. He showed that a current normally flowed in a straight line and that its flow could be obstructed by placing a solid object in its path. This projected a “shadow” on the vessel walls, which showed itself by an absence of the characteristic phosphorescence. He found only the cathode threw this shadow, which seemingly showed electric current consisting of only one-way traffic (negative electricity traveling from the cathode to the anode.)

William Crookes (1832-1919)

Crookes was the son of a London tailor who was self-taught. As a young boy he experimented in his own make shift laboratory. He grew up to be a teacher of chemistry and a scientist of great experience. Crookes became fascinated with Faraday’s theory on radiant matter and his suggestion that the luminosity of highly rarefied gases in a vacuum tube when excited by electricity was a property of matter in the fourth state. So as the German scientists labored, so did Crookes.

Crookes devised an apparatus for obtaining even higher vacuums. He used vacuum tubes in many different shapes and forms which contained terminals at both ends, which were fused on top of the glass, to examine the properties of radiant matter. He used the induction coil to supply a controllable current. He focused the rays by using a *concave* cathode. In the later 1870’s, he demonstrated many properties of the luminous rays emanating from the cathode.

While observing the electrical discharges through gases, Crooke observed the tube which initially contained air or other gas at atmospheric pressure. When the voltage source was connected to the electrodes, no effects were observed, but, as he lowered the pressure with the air pump, he first observed flickering lightening-like discharges between the electrodes which became a more uniform glow through the tube as the pressure was lowered. Upon further lowering, the glow became striated and the gas around the cathode began to glow bluish-purple. Continued evacuation showed dark spaces filled the tube and all the visible glow became extinguished, leaving only a greenish-yellow glow visible at the end opposite the cathode.

He concluded that cathode rays were negatively charged particles which produced a great deal of heat if stopped. He said the faint light, which emanated in a perpendicular line from the cathode ray surface, moved in straight lines regardless of the anode position. In low vacuum tubes he could make the bands of color turn corners and enter side tubes he placed there containing the anode electrode. He felt the fluorescence which was produced there resulted from the impact on solid materials in the ray's path. Crookes placed a maltese cross of mica metal in the ray's path and he observed a shadow projected on the tube wall behind the cross. He next placed a paddle wheel, also composed of mica, in the path and watched it turn as the particles hit it. He concentrated the rays on metal and found they generated enough heat to melt platinum. He also succeeded in deflecting these rays by bringing a magnet close.

Crookes felt the beam of the cathode ray was composed of a torrent of molecules of the residual gas in the tube. He said these were attracted to the cathode and took on a negative charge from it. Then, because of the similarity in charge, the molecules were repelled away in a perpendicular direction. The phosphorescence or fluorescent glow resulted as the charged particles hit the inner glass surface of the tube.

A controversy developed as to the true nature of the cathode ray. Crookes and his mostly English supporters felt they were emanations o particles while most German experimenters felt they were disturbances in *ether* and that they were similar to ultraviolet light. [It was not u il 1897 that J.J. Thomson would show that the cathode ray consisted of negatively charged particles (electrons) and confirm Crookes' theory]. Among those who disagreed with Crookes was Henrich Hertz. Hertz discovered cathode rays could penetrate thin metal sheets but they emerged in what he called a disturbed state. In 1892, he wrote "Cathode rays are significantly different from light rays in that they have the ability to penetrate solid bodies." Further work would be conducted by Hertz's pupil, Lenard.

As a result of his work, Crookes' tubes and induction coils were added to the classrooms in high schools and colleges across the world. Many lectures were given on Crookes tubes. Although the tubes did vary in the amount of vacuum, a majority must have been producing x-rays, but surprisingly no one discovered them. Even Crookes had noticed that photographic plates, from newly opened boxes, were often blackened and fogged. He even returned some to the manufacturer as defective. Eight more years would pass before the discovery was made.

Phillip Lenard (1862-1947)

While at the University of Bonn in 1894 and working as a student to Hertz, Lenard constructed a tube with an aluminum window sealed in the glass wall of the bulb where the cathode rays were focused. He found the stream passed through this window and into the air for a distance of approximately eight centimeters. He was thus able to bring the rays into the outside air. He found they still produced fluorescence but they did not travel very far in air at normal atmospheric pressure. He identified these rays as being cathode ray by placing a phosphorescent mineral in its path and also by magnetic deflection. In one of his observations, he stated the cathode rays passed through his hand. (This must have surely been x-rays, not cathode rays.) He also placed a photographic plate, still in its light proof holder, in the path of the ray and found it had been penetrated. What he had failed to realize was that after passing through the aluminum window, the cathode rays mixed with another type of ray, the x-ray.

II. THE DISCOVERY OF X-RAYS

In october of 1895, Wilhelm Conrad Ršntgen (1845-1923) who was professor of physics and the director of the Physical Institute of the University of Wurburg, became interested in the work of Hillorf, Crookes, Hertz, and Lenard. The previous June, he had obtained a Lenard tube from Muller and had already repeated some of the original experiments that Lenard had created. He had observed the effects Lenard had as he produced cathode rays in free air. He became so fascinated that he decided to forego his other studies and concentrate solely on the production of cathode rays.

One Friday evening, on November 8, 1895, he worked alone in his laboratory. It was the beginning of the weekend and all of his assistants had gone home. He had set up his experiment using a Crookes tube fitted with an anode and cathode , separated from each other by a few centimeters in the tube. He used a Rhumkoff induction coil to produce a difference of potential of a few thousand volts, knowing that a stream of charged particles would originate in the cathode and would be attracted to the anode.

The laboratory Ršntgen worked in that evening was very similar to all other laboratories of those who worked before him, but the conditions that existed that evening varied in three very important ways. His laboratory was dark, his tube was covered with a light-proof cardboard jacket and a screen of fluorescent material laid on a table a few feet away from the apparatus. While passing the discharge, he suddenly noticed a shimmering light on the table top. He could not believe his eyes, so he again repeated the experiment. He released the discharge many times producing the same results each time. Greatly excited, he realized that the green fluorescence was emanating from the screen. He repeated the experiment again, this time moving the screen further and further away and he still received the same results.

Ršntgen knew the fluorescence could not be produced by the cathode rays since it was well known that they could not penetrate through the wall of the tube. Visible light could not be the stimulus since the tube was covered with a shield which was opaque to light. He boldly hypothesized that he must have been producing some unknown type of radiation.

Ršntgen spent the next eight weeks in his laboratory repeating his experiments. He ate and even slept in his laboratory as he attempted to determine if the rays could penetrate substances besides the air. He placed various objects between the tube and screen and he found that the screen still fluoresced but with different intensities depending on the material being used. When he placed a lead disk, which he was holding, in the cathode ray path he was astonished to find the shadow of the round circle appeared on the screen along with the outline of his thumb and forefinger and within them the bones of his hand! He replaced the screen with a photographic plate and employed his wife Bertha to place her hand on the photographic plate while he directed the rays at it for fifteen minutes. Frau Ršntgen was taken back and somewhat frightened by the first x-ray plate of a human subject which enabled her to see her own skeleton. The feeling to her, as would come to others, was vague premonition or death.

Ršntgen hurriedly prepared his notes so that his first report “On a New Kind of Rays” could be published in the *Proceedings of the Physical Medical Society* of Wurburg on December 28, 1895. The paper consisted of some seventeen numbered paragraphs indicating various observations. Ršntgen described how he created and noticed the fluorescence of the barium platinocyanide screen. He described his amazement at the fact that something had passed through the cardboard surrounding his tube. He then described how he sought to *investigate* the transparency of other objects. He wrote on his observations of paper, a One thousand page book, blocks of wood, a sheet of tin foil, a double deck of cards, a single card, and sheets of hard rubber. He described his observation that glass plates of equal thickness behaved in different wars depending on the amount of lead they contained, those with more lead were less transparent. He described testing various metals and his finding that lead seemed to be the most opaque material. Not knowing what these emanations were he uses the term *x-ray* to describe the rays he was producing.

Ršntgen continued by describing objects which fluoresced besides the screen such as rock salt and ordinary glass. He described an insensitivity of the eye to the rays even when brought close to the tube. He wrote his attempts to pass the rays through a prism finding that no deviation occurred. He told of his attempts to defract the rays by utilizing a magnet. He wrote of his certainty that the rays were emitted from the point on the tube which fluoresced the most. By deflecting the cathode rays, he found the x-ray emanated from a new spot. He continued on to tell of some of the shadowgrams he produced. (Shadows of this type are of extreme sharpness when the source of the ray is narrowed more than those produced by light because the shadows enlarge as a result of defraction, which is almost completely absent with x-rays.) He wrote of how one shadowgram was taken through a door with the discharge apparatus on one side and the plate on the other. He concluded the paper by stating his belief that the rays were not some type of ultraviolet light.

The news spread quickly and the first newspaper report occurred as a result of a “leak”. Ršntgen had sent his friend, Franz Exner, at the Vienna University, some of his first x-ray pictures. Exner in turn showed some of his associates, one of whom was the son of the editor of the Vienna Presse. The young man borrowed the pictures and showed his father who at once realized the news value of the discovery and published an article describing the main facts as he knew them. He also included a prediction of his own of the possible medical value of the new discovery. The article was quickly copied by papers in many other countries and publications soon appeared both in Europe and the United States, even before they appeared in the local Wurburg papers.

Ršntgen was not at all pleased with the notoriety. He described, in a letter to a friend, his disgust at not being able to recognize his own work upon reading the newspaper reports and his sadness that the photographs were not viewed as a means for his discovery, but rather were treated as the main discovery. He described his inability to work free of interruption in his own laboratory.

On January 13, 1896, Ršntgen was called to give a demonstration of his discovery for Kaiser Wilhelm II. From five o’clock until midnight, Ršntgen demonstrated, using limited equipment, showing how the rays penetrated boards of paper and wood, boxes of paper, and other non-living objects. At the end, the Kaiser decorated Ršntgen with the Order of the Crown.

The first and only demonstration before a scientific group occurred on January 3, 1896. He gave an introductory review and then demonstrated the penetration powers of the x-ray. After his formal lecture, he invited a colleague, Professor R.A. von Kolliker, the famous anatomist and embryologist, to have his hand photographed. Von Kolliker was so impressed that he called for a round of cheers and proposed that the new rays be designated Ršntgen rays.

Ršntgen was a sincere and humble man of great modesty and he lid not wish his rays to bear his name. As offers of honor came to him, Ršntgen found them so very distasteful that he sought refuge in Italy in March, after the publication of his second paper. The Kingdom of Bavaria offered him the Royal Order of the Crown. The offer also meant that the word “von” would be placed before his name and he would be considered nobility. He accepted the invitation, but declined the symbol of status, the “von”. Later, in 1896, he accepted the Rumford gold medal of the Royal Society and in 1901 he would be the first to receive the Nobel Prize for physics, but he bequeathed the Nobel prize money to scientific research at Wurburg.

Just as incidents of honors were high, as was excitement, the saturation point was quickly reached by the public and interest began to wane. However, the shock of looking at a shadowgraph (as x-ray pictures came to be called) of one’s hand or head produced sensations of death and those who did not understand, saw the x-ray as an invasion of privacy. Cartoonists and jokers saw in this new discovery an area for new humor. From cartoons which appeared in the printed media, it seems clear that the general public did not receive Ršntgen’s discovery very well. The general concept seemed to indicate that Ršntgen’s photography was similar to that of regular photography, except that it was believed to penetrate every thing including flesh, clothing, bones, etc

. . . In researching, mention is often made of the fact that *Life* magazine often carried many jokes and cartoons pertaining to the subject. A London firm even advertised the sale of x-ray proof suits in one magazine. One New York newspaper report announced that the College of Physicians and Surgeons was using x-rays to reflect the diagrams directly on to the students' brains, making a more enduring impression than the normal method of learning. In New Jersey, the misconceptions spread to the House of Representatives floor when one legislator forbade the use of x-rays in opera glasses.

Ršntgen spent the ten weeks after his first publication pursuing new lines of investigation and the second paper was submitted in March, 1896. Ršntgen knew that x-rays were capable of discharging electrified bodies and he felt certain that it had been x-rays, not cathode rays in Lenard's experiments which had passed through the aluminum window. Ršntgen wanted an atmosphere free from electrostatic forces from the vacuum tube, from the induction wires, and the air which was near the discharge apparatus. He built a sheet metal cabinet approximately seven feet high and four feet square in order to create a more permanent dark room and eliminate the need to drape the laboratory with ineffective curtains and blinds. On one side he inserted a thin aluminum disk approximately eighteen inches in diameter for the rays to pass through. He also covered the wall with lead paint. He placed the discharge apparatus on the outside of this wall. He placed a zinc door on the opposite side, which allowed him to enter and exit. (This apparatus, without his knowing, would also provide Ršntgen the needed protection from x-ray radiation.)

His second paper described his discovery that electrical bodies were discharged more quickly if the rays were more intense. He described finding no difference between positive and negative electricity or conductors or insulators. Secondly, when an electric conductor was surrounded with a solid insulator, such as parafin, the radiation had the same effect as would result from an exposure of the insulating material to earth. He wrote next of surrounding the insulating material with a conductor connected to earth, noting the radiation produced no action which can be detected. These observations lead him to conclude it was the air through which the x-rays had passed which possessed the power to discharge the electrified bodies.

Ršntgen described next how he set up an experiment to show that it might be possible to discharge bodies by exposing them to air which had been exposed to x-rays. He wondered why the air lost this property. (We know the ions recombine in a short time, especially upon collision with a surface.) The paper concluded with the observed effects of an x-ray on other gases and the effects of different cathodes concluding that platinum was the best material to use to make a cathode.

Ršntgen's third and final paper on the subject was published one year later in March, 1896. It contained still more information on experiments he had conducted. Ršntgen described his finding that any substances subjected to x-rays would themselves emit x-rays. He termed this secondary radiation. Ršntgen found that with *soft x-rays* , the emission was uniform over a hemisphere on a target, while with *hard x-rays* and a thin target, some radiation appeared from the back of the target. He concluded with a number of comparative opacity to x-rays of various substances in different thicknesses.

Ršntgen went on to accept a position to head the Philosophical Faculty of the University of Munich. Here he issued seven more communications over the next seventeen years, most of which covered his former interests. In a letter to his cousin in America in 1912, he wrote about making a possible trip. However, his frail wife's health worsened, World War I broke out and the trip was never taken. His feelings for his country remained strong and when the call for gold came to be melted into buillion, he turned in his decorations, including the Rumford medal. This, it is said, he later regretted.

At the end of the war in 1919, there was bitter political unrest and considerable inflation. Ršntgen, on a fixed income, struggled to adjust to the daily rise in costs. To add to his sadness, within the year of the armistice, he lost his wife and became increasingly lonely. He continued to work until his retirement in 1920 and even then two rooms were set aside in which he continued to work. By 1923, he still walked to the laboratory but he complained that his sight and hearing were proving inadequate for observations. On February 10, 1923, he died in Munich at the age of seventy-eight of carcinoma of the intestines. In accordance with his will, his body was cremated and his papers and personal correspondences were burned. His personal belongings were auctioned off and the proceeds were turned over for educational uses.

Have students read the selection on Ršntgen contained in the slide packet and complete the worksheet in this unit.

GLOSSARY

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amber—a yellow or brownish yellow translucent fossil of resin
anode—positive electrode
armature—the revolving part in an electrical motor or dynamo
cathode—a negatively charged electrode
cathode ray—a stream of electrons projected from the surface of a cathode in a vacuum tube: these produce x-rays when they strike solids
chaff—threshed husks of wheat or other grain
concave—curved like the section of the inside of a sphere
Copernican disciple—one who believed that the sun was the center of the universe not the earth
dynamo—a device for converting mechanical energy into electrical energy by producing a relative periodic motion of a conductor and a surrounding magnetic field
effluvium—an imaginary or a real outflow in the form of invisible particles
electrode—any terminal that conducts an electric current into or away from various conducting substances in a circuit, as the anode or cathode in a battery, or that emits, collects, or controls the flow of electrons in an electron tube
electrolytes—substances in solution which can conduct an electric current by the movement of its positive ions to the negative electrode and negative ions to the positive electrode
electromagnetic theory—the concept that includes the complete range of frequencies of electromagnetic waves, including in order of increasing frequencies and decreasing wavelengths, those of radio waves, infrared light, visible light, ultraviolet light, x-rays, gamma rays, and cosmic rays
electromagnetic waves—a wave propagated through space or matter by the oscillating electric and magnetic field generated by an oscillating electrical charge
electroscope—an instrument used for detecting very small charges of electricity as by the repulsion between electrically charged strips of gold foil or other foil
ether—an invisible substance postulated as a pervading space and serving as a medium for the transmission of light waves and other forms of radiant energy
glavanometer—an instrument for detecting and measuring a small electric current
hard x-ray—one that was produced from a tube which has an extremely high vacuum, more

penetrating rays
hempen—tough fibers of a plant of the nettle family
induction coil—an apparatus made up of two magnetically coupled coils in a circuit in which interruptions of the direct-current supply to one coil produce an alternating current of a high potential in the other
lodestone—a strongly magnetic variety of the mineral magnetite
phial—a glass sphere
potential—the relative voltage or degree of electrification at a point in an electric circuit or field as referred to some other point in the same field or circuit
resinous—type of charge obtained from rubbing rubber or rubber-like material
seeds—atoms
soft x-rays—those produced from a tube of slightly lower vacuum, less penetrating rays
transparency—the ability of a substance to block x-rays
vitreous—the type of charge obtained from rubbing glass or glass-like materials
vortex—a whirling mass forming a vacuum at its center into which any thing caught is drawn into motion
x-ray—an electromagnetic ray or radiation of very short wave length, produced by the bombardment of a metal by a stream of electrons, as in a vacuum tube

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AUDIO VISUAL MATERIALS

A set of slides and a script has been prepared which parallels the material in the unit and provides additional information on the early usage of the x-ray.

The necessary reading materials have also been placed in the packet with the slides and worksheets.

WORKSHEET ANSWERS

Evangelista Torricelli

l.Evangelista 2.Galileo 3.Feanza 4.projectiles 5.three months 6.thirty-two feet 7.four feet 8.mercury 9.thirty inches 10.vacuum 11.air pressure 12.water 13.light 14.thirty-nine 15.g1ass making l6.nothing l7.mathematics

18.Caste11i 19.weight 2O.barometer

Michael Faraday

l.electricity 2.ten 3.London 4.bookbinding 5.Humphrey Davy 6.assistant 7.motor 8.fie1d 9.magnet 10.Oersted 11.Roya1 Society 12.induction 13.mercury 14.galvanometer 15.relative 16.dynamo 17.electromagnetic

James Clerk Maxwell

1.Roya1 2.fourteen 3.Scotland 4.Dafty 5.Cambridge 6.Rumford 7.mechanical 8.Faraday 9.time 10.Hertz 11.laws 12.cancer 13.forty-eight 14.Cavendish 15.closed 16.electrical 17.magnetic

Wilhelm Konrad Roentgen

1.fifty 2.Germany 3.Crookes 4.Faraday 5.air 6.electrode 7.negative 8.shadows 9.television 10.electrons 11.cardboard 12.g1ass 13.magnet 14.exposed 15.positive 16.target 17.Roentgen 18.hand 19.noble