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Prepared by: Carolyn J. Frigmanski, M.A., B.S.R.T. ®
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Carolyn J. Frigmanski, M.A., B.S.R.T. ® Founder, S.T.A.R.S.

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UNIT NUMBER 1

INTRODUCTION TO RADIATION PHYSICS

PREPARED BY: Carolyn J. Frigmanski, M.A., B.S.R.T. (R)

INTRODUCTION

DEFINITION OF PHYSICS

The science we call physics was started with Galileo Galilei in the 16^{th} century. His primary interest was the description of motion. Because physics is such a broad subject, it is very difficult to come up with a precise definition. Some people believe the best definition is "Physics is what our physicists do every day." It is undeniably true that physicists study the universe from the smallest parts of matter which are atoms to the largest which is considered the galaxies and beyond. They utilize both experimental or laboratory techniques in addition to theoretical or mathematical calculations. Some of the topics included in physics today are:

- Matter and energy
- Optics
- Mechanics
- Motion
- Electricity and magnetism
- Atomic and nuclear physics
- Gravitation
- Thermodynamics

These are just a few of the subjects investigated by physicists throughout the world. However, all of us are "physicists" to a lesser degree. For example, we utilize physics in our day to day living. We would not be able to put our automobiles in a parking place without understanding or applying basic laws of physics relative to spatial dimensions, velocity and rotation. Another example is simply washing the dishes in which we utilize principles of surface tension, maintenance of temperature with the water and space concepts in placing the dishes in the dishwasher. Although the majority of radiographers are not enthusiastic about studying physics, it does apply in our every day life and in our occupations. So let's begin the topic with a little more enthusiasm than generally perceived by educators.

MEASUREMENT AND THE METRIC SYSTEM

The basis for all scientific studies lies in the ability to measure quantities. Experiments and concepts cannot be developed without appropriate design and measurement. Scientists all over the world utilize the Systeme International (SI) to express measurements. There are eight fundamental quantities upon which all measurements are calculated.

1. Length = the unit of length is the meter which is approximately 39.36 inches.[1(p26)]

2. Mass = the unit of mass is the kilogram which has the approximate weight on earth of 2.2 pounds.[1(p26)] This standard measurement is compared to a platinum-iridium cylinder that is kept at constant temperature and humidity in a dustless vault in Sevres, France. It should be noted that mass and weight are not the same quantities. Mass is the quantity of matter contained in a physical object while weight is the force with which gravity attracts matter in its field.

3. Time = the unit of time is the second and is based on the frequency of vibrations of cesium-133 atoms under certain defined conditions.[1(pp26-27)]

4. Temperature = the unit of temperature is the Kelvin (K). This standard is based on the point at which solid, liquid and gaseous water co-exist simultaneously and is assigned a value of 273.16K.

5. Ampere = the unit of electric current is the ampere (A). This standard is based on the mutual forces experienced by parallel current carrying wires.[1(p66)]

6. Luminous intensity = the unit of measurement is the Candela (cd). This standard is based on the amount of radiation emitted by a certain object known as a black body radiator at a freezing temperature of platinum (2046K).

7. Number of particles = the unit of particle numbers is the mole (mol). This standard is based on the number of atoms contained in 0.012 kilogram of carbon-12 (6.02 x 1023 atoms).

8. Work = the product of force and distance is measured in Newton-meters (N.m). It is also called a joule (J).[1(p29)]

SPEED OF LIGHT

The speed of light was first determined in 1675 when a Dutch astronomer named Olaus Roemer used his observations of Jupiter and the eclipse of one of its moons. In the 19th century, an American physicist named Albert Michaelson used sunlight and rotating mirrors to obtain more precise measurements than his predecessors. As the result of

Einstein's special theory of relativity, we have established the speed of light in a vacuum to be constant. The standard value of 3×10^8 meters per second or approximately 186,000 miles per second. [2(p30)] The letter 'C' is used to represent the speed of light in a vacuum when working with physics formulae. The speed of light is less in a material medium than in a vacuum. Its speed can be altered by the nature of the medium and the frequency of the light waves.

ENERGY AND IT TYPES

The most widely accepted definition of energy is the ability to do work[2(p3)]. It is the product of force and the component of displacement in the direction of the force. Without motion, there can be no work. A classic example in radiography is performing portables. Obviously, energy has to be applied to the portable machine to move it down the hallways. Energy and work are both accomplished interchangeably. Power is defined as the rate at which work is performed[2(p32)]. Potential energy is defined as the capacity to do work and exist in a stored format. Potential energy is really gravity that provides an object with its energy or ability to do work and is correctly identified as gravitational potential energy, even though we usually abbreviate it as potential energy. Kinetic energy is defined as the energy an object has by virtue of its motion.

When work is performed, the object's kinetic energy (the energy associated with this motion)[2(p4)], its potential energy, (the energy associated with its position), or its internal energy (the energy associated with its atoms and molecules) must be used. Simply stated, when work is performed on an object, the energy of the object is changed. Kinetic and potential energy are collectively called the mechanical energy of the object. When pushing the portable, a force must be applied. A force is simply defined as a push or a pull in a given direction. The relationship between force and motion is provided by Isaac Newton. Forces always occur in pairs, i.e. if an object exerts a force on another object, the second object exerts an equal and opposite force on the first object. There are special categories of forces that we need to include in our understanding of physics. The first force is weight that we have described earlier as the force on an object as a result of gravitational attraction by a massive body such as a planet[2(p31)]. The second is friction which is a force resulting from the contact between two surfaces. It is understood that frictional forces are always directed so that they oppose any relative motion. I am sure any radiographer who has tried to push a portable machine over a carpeted hallway is fully aware of the force of friction and overcoming the resistance to the forward motion of the portable machine.

SOURCES OF ENERGY

There are multiple sources of energy. We will only define those that are most common in our practice of clinical radiography. The first type of energy is chemical which is defined as energy released in a chemical reaction[2(p4)]. Operating a battery-charged portable is an example of chemical energy that is created by the internal components of the battery.

A second energy type is electrical which is defined as work that may be performed when electrons move through a wire[2(p4)]. Obviously, our radiographic installations involve a great deal of electrical wiring to make it operational.

A third type of energy is thermal or heat that is considered energy of motion at a molecular level and is associate with changes in internal energy[2(p4)]. Temperature is the quantity used to measure "hotness" of a body with a thermometer. Changes in temperature result with the transfer of heat energy when two objects are brought into contact. Heat energy will be exchanged until the temperatures of the objects are equivalent. The generation of x-ray energy in the x-ray tube produces approximately 98-99% heat.

Another type of energy is nuclear which is defined as the energy contained in the nucleus of the atom[2(p4)] and is definitely utilized in the applications of radioisotopes in Nuclear Medicine.

The last type of energy, which is most important to us in our production of x-ray energy, is electromagnetic. It is energy emitted by a source and transferred through space. The primary x-ray beam is electromagnetic in nature because the source of x-rays resulted from the bombardment of the tungsten atoms in the anode by high-speed electrons from the cathode. The disruption of the stable tungsten atoms produced energy that was transferred through space in a wave-like manner.

HISTORY OF THE ATOM

There is an established understanding that matter is defined as anything that occupies space and is constructed of atoms and molecules. The modern physics concepts that have been developed for centuries are based on an understanding of the atomic structure. The earliest proposals for the construction of matter were made by the Greeks in the year 200 B.C. They described all matter as composed of four substances. The Greeks described them as earth, water, air, and fire which correlates to the Western culture of the four essences known as wet, dry, hot, and cold.

The first scientific model of the atom was conceived by an English chemist and physicist named John Dalton in 1808. His model explained the mathematics of chemical combinations and determined an element was composed of identical atoms. However, the internal structure of the atom was described as a "hook and eye" scheme very similar to the style of Victorian clothes during that time period. If you have seen the most recent release of "Titanic", you may have noticed that the clothing of the female star was closed by loops of thread placed over established buttons. Some of you may remember grandmothers who had high-buttoned shoes that required the use of a wire hook to place the loops on the stationary buttons. This structure of the atom correlates to the hooks we use on Christmas bulbs when we attach them to the loop on the glass bulb itself.

By the beginning of the 20TH century, the discoveries of Antoine Henry Becquerel, Pierre and Marie Curie, Frederic Joliot-Curie, Irene Joliot-Curie and J. J. Thomson led to the concept that the atom was constructed of positively and negatively charged particles. J. J. Thomson concluded that electrons were negative in nature and that the majority of the atom was mass. His concept correlates quite easily to our present-day practice of adding fruit cocktail to Jell-O. The electrons would represent the assorted fruit cocktail pieces and the Jell-O provided the media for the electrons. Thomson studied cathode rays produced in a partially evacuated glass tube with electrodes at both ends. When the electrodes were connected to a source of high potential difference, i.e. voltage, a greenish glow appeared at the cathode or negative terminal. Thomson concluded that the glow as produced by a flood of particles identical in charge and mass flowing out of the cathode. He called these particles electrons.

In 1911, a British physicist named Ernest Rutherford and his two assistants, Hans Geiger and Ernest Marden, bombarded a thin metallic foil, such as gold, with massive positively charged particles known as alpha particles (helium nucleus). They analyzed the tracks of the scattered particles and observed the following phenomenon:

1. Most of the particles passed through the materials without being deflected.
2. A very small number of the particles were deflected through at large angles approaching 180o.
3. The path of the deflected particles was hyperbolic in shape.

Benjamin Franklin and other physicists strongly suspected that the electrical effects were produced by the motion of minute electric charges, which was finally proven in 1897 by J. J. Thomson.

Based on these experiments, Rutherford and his co-workers formulated these conclusions:

a) most of the atom was empty space;
b) most of the mass of the atom concentrated in a dense positively charged nucleus with negative electrons orbiting the nucleus; and
c) the hyperbolic pass was the result of repulsion between the alpha particles that were positive and the atomic nuclei which was also positive.

Twentieth century physics underwent a revolution when four papers were published in 1905 by Albert Einstein, a little-known German patent examiner in Switzerland. He proposed a special theory of relativity that revolutionized Newton's long-established Laws of Mechanics. He analyzed his theories further and produced the famous equation, E = mc2, in which E equals energy, m represents mass and c is the speed of light squared. Einstein concluded that light itself exists in lumps of energy called photons.

In 1913, a Danish physicist named Niels Bohr improved Rutherford's description of atomic structure. He schematically represented atomic structure as a miniature solar system with the electrons revolving around the central core of matter known as the nucleus. He also postulated the concepts of orbits and their specific amount of energy. These energy levels have later become established as quantum numbers. He estimated that electrons account for less than one four-thousandths of the mass of the atom with most of the mass contained in the nucleus. The model of nuclear structure continues to evolve. Physicists have discovered a host of particles whose functions are largely unknown.

THE ATOM AND ITS PRIMARY COMPONENTS

All matter contains electrically charged particles, both positive and negative. These particles make up the atoms that compose the universe. The size of these atoms is of the order 10^{-10} meters[2(p38)]. Every atom is electrically neutral because it contains equal quantities of positive and negative charges. Atoms are considered the smallest part of an element that have all the properties of that element[2(p38)]. For example: Hydrogen is gas at ordinary temperatures, but it liquefies at a lower temperature. Hydrogen possesses a certain density for a given temperature and pressure. It forms certain compounds when it combines with other elements. Any material that has all the properties of hydrogen must be hydrogen.

Today, we have identified 112 elements and display them on our periodic table. Ninety-two (92) of the 112 elements are naturally occurring and 20 have been artificially produced in high-energy particle accelerators.[2(p38)] Most substances we deal with on a daily basis are not elements but compounds. Compounds are defined as the chemical combinations of two or more elements that make a new substance. If we look at water, we know that it is composed of two hydrogen atoms and one oxygen atom. Any compound can be broken into its constituent elements by chemical means. The smallest subdivision of a compound is referred to as a molecule.

The positive charge of an atom, as well as most of its mass, is concentrated at the center of the atom called the nucleus[2(pp41-42)]. The nucleus is the dense core of the atom composed of protons and neutrons, containing 99+% of the atom's mass. The nucleus is approximately 10,000 times smaller than the whole atom. It is a tightly bound cluster of two kinds of particles called protons and neutrons. The proton is a positively charged particle found in the nucleus and weighs approximately 2,000 times more than the mass of the electron. Its counterpart in the nucleus is the neutron which is electrically neutral and of an equivalent weight.

The electron is a negatively charged particle that revolves around the nucleus at nearly the speed of light[2(pp41-42)]. Electrons revolve around the nucleus in all directions and in all planes. Since the electrons revolve around the nucleus of the atom, they form its outer "surface" and determine what other atoms their atom will combine with and in what ratio the combinations will be made. Therefore, electrons determine the chemical properties of the element. The number of electrons an atom has revolving around its nucleus is normally equal to the number of protons in the nucleus. The atom is then described as neutral. Although the atom may momentarily loose or gain an electron, the number of protons in the nucleus cannot be changed by ordinary means. When an atom has a fewer or greater than normal number of electrons, it is called an ion. When an atom has a fewer or greater than normal number of neutrons, it is called an isotope.

Particle	Relative Charge	Charge (C) coulomb	Mass (kg)
Proton	+1	$+1.60 \times 10^{-19}$	1.66×10^{-27}
Electron	-1	-1.60×10^{-19}	9.11×10^{-31}
Neutron	0	0.00	1.67×10^{-27}

Contemporary physicists have identified 100 subatomic particles found in the nucleus. Some of these particles are named neutrinos and antineutrinos, antiparticles, hyperons, and hadrons, etc. It has been suggested that protons and neutrons are composed of smaller particles. Experimental tests have been conducted by bombarding protons with high-energy electrons to observe the scattering pattern. There is clear evidence to support that protons have some kind of internal structure. A model has emerged in which these smaller particles are called quarks.

ELECTRON SHELLS OR ORBITS

There are two principle forces that keep electrons in their precisely fixed orbits in relationship to the nucleus. The electron binding energy refers to the position of the electron to the nucleus. The closer the electron is to the nucleus, the higher is its binding energy. Electrons are also attracted to the nucleus by a center seeking force. Both centrifugal and centripetal forces keep the electron in its associated orbit. The electron shells or orbits have a specific capacity of electrons and have been identified with a letter from the alphabet. The K shell, which is closest to the nucleus, holds a maximum of two electrons. L shell holds eight. M shell holds 18. N holds 32. O has 50. P has 72. Q shell, the last shell identified with our current body of knowledge, has the capacity of 98 electrons.[2(p43)] It is the farthest shell from the nucleus. There is a tendency of atoms to want to have its outer electron level full. This tendency is used to explain some of the chemical behavior atoms possess in forming compounds. Whenever an atom has eight electrons in its outermost shell, it is referred to as an octet. Electron shells or orbits that have less than eight electrons residing in them are called valence electrons. Valence electrons are important because they provide our current foundation in understanding chemical binding.

PERIODIC TABLE

In 1858 Dmitri Mendeleev developed the first periodic table of 58 elements. Each element has been given a chemical nomenclature and abbreviated form. For example, Hydrogen, the first element, is abbreviated with capital H. The elements are arranged in horizontal rows that indicate the order of atomic number or the number of protons. Elements with similar properties have been placed in the same vertical column that is described as a group. The group corresponds to the number of electrons in the outermost shell or orbit. Let's look at the element Sodium. It is in group 1. There is one electron in the outermost shell. It is in period 3. There are three electron shells. If we wanted to diagram Sodium in a Bohr model, we would show the nucleus and the three orbits. The first orbit, K shell, would have two electrons, L shell, the next orbit would have eight, and the M shell would have one electron. Other information surrounding the name of the element in the box is the atomic number. It is the superscript, the number located above the element's abbreviation. The superscript represents the number of protons in the nucleus. With our simplistic model, we would add 11 protons to the Sodium nucleus.

The subscript, or the number located below the chemical name, is the atomic mass number. This number represents the total number of nucleons, i.e. protons and neutrons. Therefore, if we subtract the atomic number of Sodium, which was 11, from the atomic mass number of Sodium that was 23, we would be able to ascertain that Sodium has 12 neutrons in the nucleus and identify that as such on our diagram. The Periodic Table provides a valuable amount of information to us in understanding molecular structure. Group 8 or Group 0 is considered the noble or inert gases. These gases have eight electrons in their outermost shell. Their shells have been "satisfied" and have no need to share electrons with nearby atoms. Therefore, they do not react chemically with other atoms.

In creating compounds, electrons can be bound in two processes. An ion is an atom that has either gained or lost an electron. If an atom gains an electron, it becomes negatively charged because it has more electrons than protons in its nucleus. If an atom looses an electron, it because positively charged because there are more protons in its nucleus than electrons in its outermost shell. Let's look at table salt that is a molecule composed of Sodium and Chlorine. Sodium is located in group 1 that indicates that it has one electron in its outermost shell. Chlorine is located in group 7 that indicates that it has seven electrons in its outermost shell. It is much easier for Sodium to give up one electron than for Chlorine to give up its seven electrons. Therefore, an ionic bond can form between these two elements to create Sodium Chloride. When Sodium gives up its one electron, it becomes positive, and when Chlorine accepts the electron, it becomes negative. In this ionic bonding process an atom gives up an electron and another atom gains an electron.

The second method of bonding is called covalent in which atoms share their valence electrons. Neither element gives up or receives electrons from its partner atoms. Water is a classic example of this type of bond. Water, as we know, has two Hydrogen atoms with one Oxygen atom. Hydrogen is in group 1 on the Periodic Table that indicates it has one electron in its outermost shell. Oxygen is in group 6 that indicates it has six valence electrons. For an octet to form, we need to have two Hydrogen atoms share their electrons with the six electrons in one Oxygen atom. In this manner, the Hydrogen and Oxygen atoms share the octet.

Please refer to the Periodic Table at the conclusion of this unit.

LAW OF CONSERVATION OF ENERGY AND MATTER

One of the greatest laws that has been postulated in physics is the relationship between energy and matter. This law states that energy and matter can neither be created nor destroyed, but can be transformed from one form to another.[2(p68)] If we look at the light bulb, we will see that electrical energy is required to turn the light on. The electrical energy converts to heat and light and when we turn the light bulb off, the light and heat energy dissipates from our visibility. X-ray energy is produced by electrical energy that interacts with the target atoms of the anode of the x-ray tube.[2(p143)] During this disturbance process of the stable tungsten atoms, heat and x-ray energy is produced.

ELECTROMAGNETIC WAVES AND THE SPECTRUM

Thomas Shelling performed experiments that showed conclusively that light has wave characteristics in the early 1800's. It wasn't until the middle of the 1800's that the nature of the wave was discovered by James Clerk Maxwell who was doing theoretical work on electricity and magnetism. His work led us to the predictability of the possibility of the existence of electromagnetic waves, i.e., waves given off when electrical charges are vibrated in a wire. In the course of his experimentation, he calculated the predicted speed of the electromagnetic waves as 3.0 x 108 meters per second that is the same as the speed of light. We have concluded that photons are the smallest quantity of any type of electromagnetic radiation. Electromagnetic radiation possesses both electric and magnetic properties. Electromagnetic waves of many different wavelengths can be produced by a number of different processes. Let's discuss each form of identified electromagnetic wave from longest to shortest wavelength and display them on a corresponding chart.

1. Radio waves are produced by electronic circuitry. The longest waves are used in the AM broadcast band while the very high frequency waves are used in FM, television and microwaves.[2(p62)]

2. Infrared waves emitted by warm objects are produced by the random thermal motions of molecules.

3. Visible light occupies a very small portion of the spectrum and is produced by changes in the energy levels of the outer electrons in atoms. Visible light can be split and displayed in a color spectrum with red, orange and yellow having longer wavelengths than green, blue, violet or ultraviolet.[2(pp61-62)]

4. Ultraviolet rays are produced in a manner similar to visible light except the wavelength is too short to enter the human eye. They cannot pass through the lens of the eye.

5. X-rays are produced by energy transitions from the innermost electrons of larger atoms[2(p142)] and gamma radiation is produced from the nucleus.

6. Cosmic rays are the most penetrating of all forms of identified electromagnetic radiation due to their shortest wavelength.[2(p62)]

Contemporary physicists have now established that electromagnetic radiation has a dual nature in the fact that it may behave as a waveform of energy, in addition to, possessing characteristics similar to particle activity. We will use the abbreviation EMR to represent electromagnetic radiation.[2(p63)]

Please refer to the chart at the conclusion of this unit.

EMR TERMS OF IMPORTANCE

Since we have identified electromagnetic radiation in various wave magnitudes, we need to describe some terms that relate to our ability to place these on the electromagnetic spectrum. The waveform symbol that we use is called a 'sine wave'[2(p57)]. Frequency is defined as the rate of rise and fall of a sine wave and is usually identified as oscillations of cycles per second[2(p58)]. We commonly identify one cycle as 1 Hertz. Amplitude corresponds to the height of the wavelength. Wavelength refers to the distance between two successive peaks or from one crest to another[2(p59)]. The electromagnetic spectrum was designed to accommodate the display of those energies with the wavelength and frequency. Radio waves have long wavelengths and low frequency while x-rays have shorter wavelengths and greater frequencies. Velocity is the only constant. Velocity equals frequency x wavelength and corresponds to the speed of light. Velocity, wavelength, and frequency relationship may be expressed as V=(F)(W). Wavelength and frequency are inversely proportional at a given velocity. Energy, wavelength, and frequency are inter-related. Energy increases as frequency increases while wavelength decreases.

SOURCES OF RADIATION

There are two sources of radiation in our universe.[2(p5)] The first source of radiation is considered natural or environmental and consists of cosmic (from the sun), terrestrial (from the earth) containing elements of uranium and thorium, radon gas (in the atmosphere), radionuclides, and Potassium-40 which is found in the human body!

The second source of radiation is man-made and involves the application of x-rays for medical purposes, nuclear power plants, and industrial sources.

TYPES OF IONIZING RADIATION

We have identified two major types of ionizing radiation. Particulate radiation has energy and matter associated with it.[2(p53)] For example, an alpha particle is a helium atom that has lost its 2 K shell electrons. Helium on the Periodic Table is in period 1 indicating it has one shell. Group 2 indicates it has two electrons. We know that the K shell has a maximum capacity of two. If a helium gas atom has its two electrons taken away, it now becomes an alpha particle. The alpha particle is positive in its charge because of the two protons. Beta particles are high-speed electrons and are negative in its charge.

The second category of ionizing radiation is electromagnetic radiation. This form of radiation has energy and no matter or charge associated with it. Electromagnetic radiation travels at the speed of light. It is considered an energy disturbance in space that provides the basis for our concepts relative to photons. It is important for us to realize that x-rays originate from the disturbance of bound electrons in the atom while gamma radiation originates from disturbances of the nucleus of the atom.[2(p53)] Both x-rays and gamma radiation have very short wavelengths and great penetrating ability that allows us to utilize it to the maximum in diagnostic medical radiography and nuclear medicine procedures. Gamma rays are identical to X-rays in every way except their origin—X-rays originate from outside the nucleus while gamma rays come from inside the nucleus. Because gamma rays are emitted with energies in the megavoltage range, the best radiation protection against it is distance, followed by heavy local source shielding. Wearing a typical lead apron would actually increase one's exposure in the presence of gamma radiation because the gamma rays would undergo Compton and photoelectric interactions with the lead atoms of the apron, creating lower energy characteristics and scatter radiation which causes more biologic damage.

IONIZATION BY ALPHA AND BETA RADIATION

As an alpha particle passes close to the atom, its positively charged nature attracts the electrons in the orbits of the atom. It can cause the electron to be jerked away from the atom's electrostatic field. The electron will probably not catch the alpha particle because the alpha particle travels at great speeds. The electron is simply separated from the atom. The alpha particle leaves behind a free electron and the positively charged atom. When an alpha particle stops, it picks up two free electrons from the surrounding matter and becomes a stable atom of helium.[2(p53)] It was this process by which the nature of alpha particles was discovered. Sealed containers of helium gas showed up with radioactive sources inside.

A beta particle is a high-speed electron.[2(p53)] As it passes by atoms, it exerts a repulsive force on the electrons bound in the orbital shells. The result is the same. A path of ionization is left behind by the beta particle. Beta particles have only half the charge of the alpha particle and therefore are more penetrating. A beta particle has a range hundreds of time greater than that of an alpha particle of the same energy. The alpha particle that has the most charge causes the most ionization events for each centimeter of matter through which it passes. This is one of the reasons that the range of alpha particles is only a few centimeters of air. The mass of the alpha particle is nearly 7500 times the mass of the beta particle. The alpha particle exerts a force on the electron for a far greater time as it passes by. This allows the alpha particle more opportunities to knock electrons free from their bound orbits. The primary cause of the interaction between the radiation particles and the electrons of the matter through which it passes is the electric charge of the particles.

UNITS OF IONIZING RADIATION

The four units of radiation have been established by the International Commission on Radiologic Units and issued in the French title of Systems Internationale de Units as universal standards throughout the world.

The first unit of radiation is Roentgen (R) or Coulomb/Kilogram (c/kg). It is equal to the radiation intensity that will create 2.08×10^9 ion pairs in a cc. of air.[2(p24)] The output of x-ray units is specified in mR or milliroentgen (1/1,000 of a Roentgen). The important concept of the Roentgen is to realize it is a dose of radiation that is measured in air. The radiation emitted from the target of the x-ray tube to the patient's body surface is in Roentgens. The Roentgen was given its name based on the contributions of Wilhelm Konrad Roentgen. 1 Roentgen equals 93 ergs of energy per gram.

The second unit is the Rad or Gray (Gy). It is a quantity of radiation received by a patient and represents a radiation absorbed dose of 1×10^{-2} Gy = 1 Rad.[2(p24)] The Rad is the conversion of Roentgen in the primary beam as it enters the patient's body. It is absorbed differentially based on the patient's tissue thickness and density. Rad or Gray is always used at the standard of reference in discussing the biological effects of radiation a patient or victim may receive.

Radiation damage depends on the absorption of energy from the radiation and is approximately proportional to the concentration of absorbed energy in tissue.

The gray is universally applicable to all types of ionizing radiation dosimetry-irradiation due to the external fields of gamma rays, neutrons, or charged particles, as well as that due to internally deposited radioisotopes. 1 Rad equals 100 ergs of energy per gram.

The third unit is the Rem or Sievert (Sv). It is a quantity of radiation received by the radiation worker as dose equivalent and represents 1 x 10-2 Sv = 1 Rem. The practical application of the Rem to medical radiographers is in the official report provided by the personnel monitoring device company in which film badge readings are measured in milliRem. Rem = (Rad)(Quality Factor).

The sievert, Sv, is used for radiation protection purposes, for engineering design criteria, and for legal and administrative purposes. The dose equivalent, expressed in sieverts, considers the quality factor, QF, of the radiation as well as the absorbed dose. The dose equivalent is defined as H(Sv) = D (Gy) x QF

The quality factor value is proportional to the ionizing power of the radiation being measured. Generally, the amount of biological damage produced by a particular type of radiation is directly proportional to its ionizing power. Radiation with higher ionizing power will deposit its energy in a shorter path length as it travels through biological tissue. The following table compares QF values of different radiations.

Radiation	QF
X-Rays	1
Beta-rays and electrons	1
Thermal neutrons	5
Fast neutrons	5 to 20 (energy dependent)
Protons	5
Alpha particles, fission fragments, heavy nuclei	20

The last unit of radiation measurement is the Curie or Becquerel (Bq).[2(p24)] It is a quantity of radioactive material and represents 3.7 x 1010 Bq = 1 Ci. Its name was given due to the tremendous respect and contributions of the Curies and Antoine Becquerel.

In 1896, a French physicist named Andre Becquerel was experimenting with uranium. He noticed that the uranium emitted invisible rays that were able to penetrate solid matter and expose photographic film. These invisible rays were initially given the name Becquerel Rays in honor of their discoverer. These Becquerel Rays could not penetrate dense material very well so the uranium was enclosed in a lead block with a hole in one side to create a beam-like pattern.

In 1912, it was discovered that atoms of the same element sometimes differed in their mass number. These different types of atoms of the same element are called isotopes of the element. After the neutron was discovered in 1932, scientists identified the number of neutrons in the nucleus result in various isotopic forms of the same element.

Historically, the first detection of radiation was based upon the fact that it was able to expose photographic film. Radioactivity has thereby been described as atoms that exist in an abnormally excited state characterized by an unstable nucleus due to the number of neutrons. These atoms are synonymously called radionuclides or isotopes.

RADIOACTIVE DECAY LAW

Radioactive disintegration/decay is a series of naturally occurring spontaneous nuclear emission of particles and energy that transform it to another atom.[2(p48)] In alpha decay, positive particles are ejected from the nucleus. This allows the isotopic form of the element to transform to another atom. In beta decay and positron emission, negative and positive beta particles respectively are ejected from their parent nuclei, which allows the process of transmutation to occur. In electron capture, a nucleus absorbs one of the inner electrons surrounding it. In gamma decay a nucleus ejects a gamma photon, thereby, lowering the nuclear energy of the atom.

Radioactive decay occurs according to strict mathematical laws that we have termed the radioactive decay law or half-life.[2(p49)] The half-life of a radioactive substance is the amount of time required to reduce a sample of the radioactivity material to one-half its initial value. Half-life may occur in less than a second or may result in thousands of years. For example, Cobalt-60, which we previously used in radiation therapy, had a half-life of five years. Radium has a half-life of 1,620 years.[2(p49)] As radium goes through its decay process, it transmutates to radon gas and then eventually decays down to stabilize as a form of lead.

Nuclear reactions can be induced by bombarding nuclei with subatomic particles such as a large positive alpha particle. The energies of the bombarding particles needed to produce a reaction are achieved by introducing the particles into an accelerator such as a cyclotron. Only charged particles can be accelerated in this manner. When a neutron bombards certain heavy nuclei, a fission reaction results in which the nucleus splits into two nuclei of similar size with the release of large quantities of energy. Nuclear fission produces more neutrons that can be used in turn to bombard other atoms creating a chain reaction. This process of fission is used to harness energy created to generate electricity. It was this process which allowed physicists to create Atomic bombs. Energy may also be produced by forcing like nuclei to combine in a process described as nuclear fusion. At present, physicists are experimenting with ways to control fusion and to build fusion reactors as energy sources. The stars in the sky use fusion reactions to produce their immense energies of light in our universe.

THE X-RAY BEAM

Since the earliest discoveries of x-rays, we have provided names to describe the x-ray beam. When utilizing the term "primary x-ray," we are referring to the radiation that is created from the source to the patient. When we utilize the term "secondary or scattered radiation," we are describing changes in the direction of the primary x-ray beam after it interacts with the patient. Remnant radiation is any radiation that remains after passing through the patient and ultimately reaching the film.

ATTENUATION

Attenuation, and its earlier used synonym, absorption, relates to the reduction in the number of primary x-rays that remain in the beam after penetrating through a specific thickness of tissue in the patient.[2(p582)] The attenuation, or absorption, differences can be affected by the atomic number of the atoms in the tissue. Since bone is composed of calcium and phosphorus with higher atomic numbers, the absorption of the primary beam is greater and the resultant image appears white on the film. Soft tissue is predominantly water and water is made of hydrogen and oxygen. When we compare the atomic numbers of elements found in soft tissue, the absorption or attenuation of the primary beam is less and the resultant image has a gray appearance.

The second factor to consider relative to the patient's tissue is the mass density of the atoms.[2(p173)] For example, the compact nature of bone is greater than the somewhat flaccid nature of muscle. Therefore, the attenuation or absorption of the primary radiation in the bone will be higher than the attenuation or absorption in soft tissue. The differences in this attenuation allow us to demonstrate the various tissue structures within an anatomic part. We use the term 'radiopaque' to describe tissues or structures that do not allow the passage of x-rays very easily.[2(p65)] Their appearance is white on the resultant image. We use the term radiolucent to describe tissues or structures that allow x-rays to pass through them very easily. The resultant image appears black. There are five major density differences in the human body. Tooth enamel is the most dense tissue form in the human body and appears white on our dental radiographs. Bone is the next most dense tissue and is radiopaque on our resultant radiographs. Muscle and fat are less dense than tooth enamel and bone and are portrayed as shades of gray on the resultant film. The least dense material in the body is gas that is found in our GI tract, sinuses, etc., and allows the x-rays to pass through them very easily. The gas provide us the black densities we see when filming body parts in these regions.

PROPERTIES OF X-RAYS

One year after his discovery of x-rays, Wilhelm Konrad Roentgen published a paper in which he identified the 12 properties of x-rays. These properties are still true today and are listed for your reference below.

1. X-rays are highly penetrating, invisible rays.
2. X-rays are electrically neutral.
3. X-rays are polyenergetic (possessing many energies) and heterogenous (originating from different energies).
4. X-rays liberate minute amounts of heat on passing through matter.
5. X-rays travel ordinarily in straight lines.
6. X-rays travel at the speed of light.
7. X-rays ionize gases indirectly by removing electrons.
8. X-rays cause fluorescence in certain crystals that is the foundation for our intensifying screens.
9. X-rays cannot be focused by a lens because they penetrate through the lens.
10. X-rays affect photographic film, the fundamental principle that allows us to portray images to the human eye.
11. X-rays produce chemical and biological changes, which necessitates our understanding of radiation biology and protection.
12. X-rays produce secondary and scatter radiation that necessitates our need to learn to control these forms of radiation because they reduce image quality.

X-RAY INTERACTIONS WITH MATTER

It is important for us to understand the five major x-ray interactions with matter because the matter we expose to radiation is human tissue. The understanding of these five principal interactions provides a greater understanding of the cellular and molecular changes that may result when radiation passes through living tissue. The five interactions are:[2(p165)]

1. Classical/coherent scattering
2. Compton Effect/Scattering
3. Photoelectric Effect with true absorption
4. Pair Production. We will discuss this interaction, but I want to sensitize you to the fact that this interaction does not occur in diagnostic radiography because the minimum energy level for it to occur is 1.02 Mev, (Mev equals 1 million electron volts).
5. Photo disintegration. We will discuss this interaction, but I want to sensitize you to the fact that this interaction does not occur in diagnostic radiography because the minimum energy level for it to occur is 10 Mev, (Mev equals 1 million electron volts).

The Compton and Photoelectric Effect with true absorption occur in our diagnostic range of kV (kilovoltage) to promote the scales of contrast on our finished radiographs.

CLASSICAL/COHERENT SCATTERING

When x-rays reach the proximity of the stable atom in a body tissue, the negative electrons in the body tissue will have an electrostatic field that is negative.[2(p165)] The central portion of the atom called the nucleus is positive. When the incident or incoming x-ray interacts with this stable electrostatic field, it will create a change in the path of the incident photon. The incident photon (incoming x-rays) have less energy than the electron's binding energy. The incident photon creates some momentary excitation within the atom. The incident photon has its direction slightly modified, but retains its original energy. The probability of this interaction is practically 0 above 10 kV and is unlikely to occur in diagnostic range.

COMPTON EFFECT/SCATTERING

The photon theory of light and x-rays was strongly supported by the experiments of Arthur Compton, an U.S. physicist. Compton bombarded a block of graphite with x-rays of known frequency and discovered that both electrons and x-rays emerge from the block in different directions. The incoming or incident x-rays ionize the atoms of the graphite block just as they would human tissue.[2(p165)] The emerging x-ray was changed in direction with a loss of energy or lower frequency than it originally possessed. To create its ionizing ability, a bound electron was released from its energy shell and became known as a Compton or recoil electron. The atom that received the incident x-ray was ionized and needed to fill the vacancy with another electron. Two possibilities resulted. Electrons from the other shells can drop down to fill the vacancy. Due to the difference in energy levels of the electrons, characteristic radiation is produced. The second option is for a free electron in space to fill the vacancy. All atoms in nature want to be electrically neutral. The net result of this interaction is ionization of an atom, the emission of a longer wavelength secondary x-ray and the Compton recoil electron production.

PHOTOELECTRIC EFFECT WITH TRUE ABSORBTION

In this interaction, the incident or incoming x-ray is absorbed by one of the inner shell electrons.[2(p167)] This incident x-ray has to have enough energy to overcome the binding energy of the electron to the nucleus. When the electron and the photon combine, they are described as a photoelectron. The photoelectron possesses energy nearly equal to the bond electron and the scattered radiation that is produced. Since the electron gets absorbed by the incident photon, the atom is ionized. All atoms tend to be electrically neutral so the vacancy must be filled by another electron. Usually electrons from the outer shell begin a downward transition to fill the vacancy. Low energy characteristic radiation is emitted. As the electrons relocate in the shells, the atom eventually reaches stability. The probability of this interaction decreases with increasing kVp in the diagnostic ranges, but increases with increasing atomic numbers of target atoms.

PAIR PRODUCTION

Pair production is a classic example in demonstrating the Law of Conservation of Energy and Matter. It is the only interaction that involves highly energetic x-rays interacting with the electrostatic field of the nucleus.[2(p170)] As the incident or incoming x-ray approaches the nucleus, it disappears and creates two electrons. These two electrons are called a positron (+) and negatron (-). This is the first transformation of converting energy to matter. The incident x-ray has to have an energy of 1.02 Mev to overcome the binding energy from the nucleus. The positron and negatron continue in space until the positron finds a negative particle and the negatron finds a positive particle. At that time, the particles combine to create what is described as an annihilation reaction. The result of an annihilation reaction is the conversion of these 2 particles to 2 daughter photons having an energy level of 0.51 Mev.[2(p170)] This second transformation is converting matter to energy again. Note that the incident photon of 1.02 Mev has now been transformed to two daughter photons of 0.51 Mev. This interaction does not occur in diagnostic radiology, but it does occur in radiation therapy energy levels. The net result of this interaction is an atom with an altered nuclear state and secondary ionization events that may occur by the photon pair.

PHOTODISINTEGRATION

Photodisintegration involves x-rays with energies in excess of 10 Mev.[2(p170)] The incident z-ray is absorbed directly by the nucleus, causing excitation and an instantaneous emission of either a nucleon or other nucleus fragment.

Since this interaction rarely occurs in diagnostic radiography, we will not elaborate on it to any great degree.

Please refer to the charts diagramming each interaction at the conclusion of this unit.

CONCLUSION

In addition to ionization, radiation can tear molecules apart. The destruction of molecules may cause the death of cells in the body. Since the body naturally replaces cells, a certain amount of radiation can be tolerated. We are continually being irradiated by a number of sources of radiation in the natural/environmental category. There is some disagreement as to whether there is a threshold below which there is no permanent damage. Mankind has always co-existed with some degree of background radiation. Damaged body cells cannot perform their normal function. Sometimes the body suffers from the inability of the cells to carry on an essential function. Rather than killing the cell, radiation may cause it to reproduce at a greater rate. The cell then becomes cancerous. If not stopped, it may end up killing the entire body.

Radiation can also induce damage to reproductive cells that determine the characteristics of future offspring. Radiation can induce changes that are passed on from one generation to the next. These radiation-induced changes are considered mutations and are generally harmful or even lethal.

It must be remembered that radiation can also be used medically for tracing the progress of various substances through the body. The radioactive isotope is traced to a target organ with a radiation detector. Radioactivity can produce the same effects on cellular tissue as radiation from the x-ray tube.

This concludes unit 1. Please proceed to the unit questions and complete the required personal data.

PERIODIC TABLE OF THE ELEMENTS*

(Numbers in parentheses indicate the mass number of the longest-lived isotope of radioactive elements)

Outer electrons are in the	Group I	Group II	Group III	Group IV	Group V	Group VI	Group VII	Group VIII			Group 0	Electrons per shell
Period 1 or K-shell	**1 H** 1.00797										**2 He** 4.0026	2
Period 2 or L-shell	3 Li 6.939	4 Be 9.0122	5 B 10.811	**6 C** 12.01115	7 N 14.0067	**8 O** 15.9994	9 F 18.9984				10 Ne 20.183	2, 8
Period 3 or M-shell	11 Na 22.9898	12 Mg 24.312	**13 Al** 26.9815	14 Si 28.086	15 P 30.9738	16 S 32.064	17 Cl 35.453				18 Ar 39.948	2, 8, 8
Period 4 or N-shell	19 K 39.102	20 Ca 40.08	21 Sc 44.956	22 Ti 47.90	23 V 50.942	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.71		
	29 Cu 63.54	30 Zn 65.37	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	**35 Br** 79.909				36 Kr 83.80	2, 8, 18, 8
Period 5 or O-shell	37 Rb 85.47	38 Sr 87.62	39 Y 88.905	40 Zr 91.22	41 Nb 92.906	42 Mo 95.94	43 Tc (99)	44 Ru 101.07	45 Rn 102.905	46 Pd 106.4		
	47 Ag 107.870	48 Cd 112.40	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	**53 I** 126.9044				54 Xe 131.30	2, 8, 18, 18, 8
Period 6 or P-shell	55Cs 132.905	**56 Ba** 137.34	57 - 71 La series*	72 Hf 178.49	73 Ta 180.948	**74 W** 183.85	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.09		
	79 Au 196.967	80 Hg 200.59	81 Tl 204.37	**82 Pb** 207.19	83 Bi 208.980	84 Po (210)	85 At (210)				**86 Rn** (222)	2, 8, 18 32, 18, 8
Period 7 or Q-shell	87 Fr (223)	**88 Ra** (226)	89-103 Ac series **	104 Ku (260)								

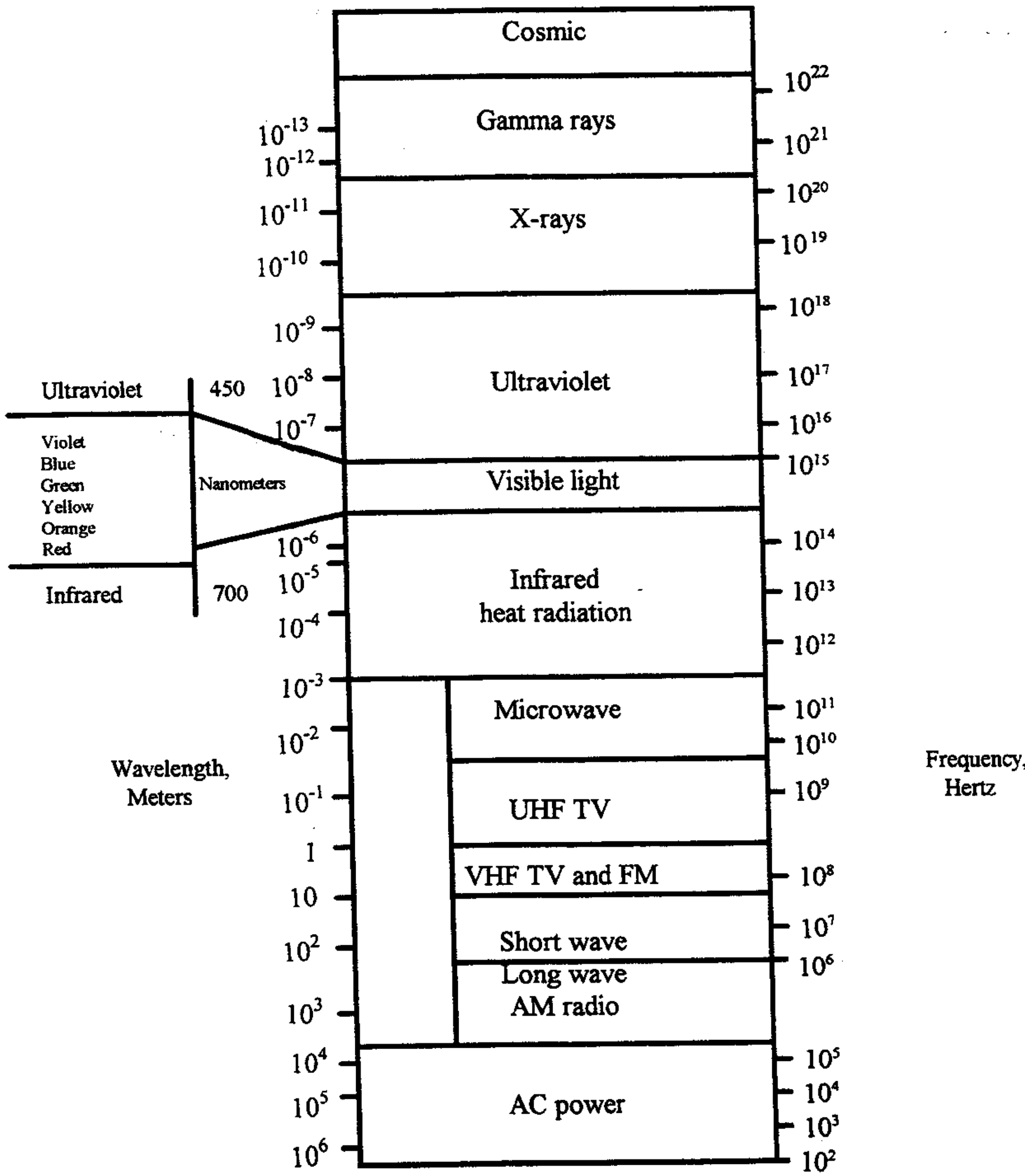
Elements 105, 106, 107, and 108 have been identified, but details are not available at this time.

*Lanthanide series:	57 La 138.91	58 Ce 140.12	59 Pr 140.907	60 Nd 144.24	61 Pm (145)	62 Sm 150.35	63 Eu 151.96	64 Gd 157.25	65 Tb 158.924	66 Dy 162.50	67 Ho 164.930	68 Er 167.26	69 Tm 168.934	70 Yb 173.04	71 Lu 174.97	2, 8, 18, 32, 9, 2
**Actinide series:	89 Ac (227)	90 Th 232.038	91 Pa (231)	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (254)	100 Fm (257)	101Md (256)	102 No (255)	103 Lw (257)	2, 8, 18, 32, 32, 9, 2

Vertical columns (Groups) = Number of electrons in the outermost shell. These elements have similar properties.

Horizontal rows (Periods) = Number of electron shells in the atom's structure. They are arranged in order of atomic numbers.

Group O (Noble Gases) = These gases are chemically inert because none of them react readily with another element. Each gas has an octet.



The Electromagnetic Spectrum

The top of the chart indicates the electromagnetic waves with the shortest wavelengths and greatest frequencies and continues down to the longest wavelengths and longest frequencies.
As the wavelength gets shorter, the more penetrating the radiation will exist.

Types of Ionizing Radiation in Summary Format for your Reference

Table 1 Particulate Radiation

Name	*Atomic Mass Unit*	*Charge or Polarity*	*Brief Description*	*Source of Origin*
Alpha	4	+2	helium nucleus	radioactive decay & heavy atoms
Beta or negatron	0.00055	-1	negative electron	radiative decay & interactions of x-ray photons
Beta or positron	0.00055	+1	positive electron	radioactive decay & pair production at 1.02 MeV or higher
proton	1	+1	hydrogen nucleus	Van de Graaff generators & cyclotrons
neutron	1	0	neucleus of atom	atomic reactors & cyclotrons
heavy neucleus	varies	varies	ionized atoms	linear accelerators
pi-meson	0.15	-1	negative particle	linear accelerators

Table 2 Electromagnetic Radiation

Name	*Atomic Mass Unit*	*Charge or Polarity*	*Brief Description*	*Source of Origin*
cosmic	0	0	shortest wavelength & most penetrating EMR	sun, stars and other astronomical bodies
gamma	0	0	used productively in Nuclear Medicine & Radiation Therapy	nucleus in radiactive decay process
x-ray	0	0	used in diagnostic imaging	ionization of tungsten atoms in x-ray tube
ultraviolet	0	0	used in dermatology	electron disturbance of atom
infrared	0	0	used in thermography	electron disturbance of atom
microwave	0	0	used in hyperthemia therapy	electron disturbance of atom

Synopsis of the Basic Interactions of Radiation and Matter

Name of Interaction	Description/Sequence of Events	Probability of Occurrence	Net Results
Coherent/Classical or Thompson Scattering	low energy incident photon interacts with an electron in a target atom, causing it to become momentarily excited; photon has equal energy but an altered direction results	unlikely in the diagnostic range	no change in target atom; no change in incident photon energy and slight change in incident photon direction.
Photoelectric Effect with True Absorption	incident photon energy must be equal or greater than an inner shell electron in the target atom; the atom gets ionized and a photoelectron is ejected from the K-shell of the target atom; characteristic radiation is produced as electrons make transitions to other energy shells to eventually become stable.	decreases with increasing kVp in diagnostic range; increases with increasing atomic number of target atoms. This interaction is 7 times greater in bone than soft tissue to enhance contrast in our resultant images.	ionization of the atom, production of a photoelectron and characteristic radiation. Sum of all the characteristic radiation energies produced must equal the binding energy of the shell the photoelectron originated in.
Compton Effect/Scattering	incident photon has greater energy than the binding energy of an outer shell electron in a target atom; the target atom gets ionized with the ejection of a Compton or recoil electron; the incident photon continues in a new direction with reduced energy; characteristic radiation is produced as electrons make transitions to other energy shells to eventually become stable; excess photon energy is emitted as secondary or scatter.	decreases as kVp increases; it is dependent on the total number and density of electrons in the absorbing tissue; dominant interaction in soft tissue.	ionization of atom; emission of scatter radiation in an altered direction & characteristic radiation.
Pair Production	incident photon energy has to exceed 1.02 MeV; photon approaches nucleus and disappears with the emission of 2 daughter particles (the positron is + and the negatron is -); the daughter particles go off in space to combine with a particle of the opposite polarity and an anniliation reaction occurs with the production of 2 daughter photons; each photon has 50% of the incident photon's energy or 0.51 MeV.	0 in diagnostic radiography	only interaction involving the nucleus; exemplifies the Law of Conservation of Matter & Energy.

Some Important Terms and/or Concepts in Unit 1

Atom

- the smallest particle into which a substance can be divided by chemical means, or it is the small particle of an element that has the chemical properties of an element.

Atomic number

- numbering and arranging of atoms (of elements) according to the number of electrons in its orbit — or said another way, the number of protons in the nucleus.

Atomic weight

- arranging of atoms (of elements) according to the number of protons and neutrons in the nucleus.

Dosimetry

- the concept and measurement of quantity of radiation, either by various sources or absorbed by body tissues.

Electron orbits about the nucleus

- designated 'K', 'L', 'M', etc. from the inner orbit out.

Ionization

- refers to the electrical imbalance in an atom when it gains or loses an electron from its orbits or an electron changes orbits.

Isotopes

- atoms that are alike in every way except in atomic weight that varies slightly because of different neutron number.

Matter

- anything that has weight and occupies space.

Molecules

- a chemical combination of two or more atoms to form a specific chemical substance, or it is the smallest particle into which a substance can be divided by mechanical or physical means and retain its properties.

Periodic table

- shows the relationship of atoms (of elements) arranged according to their atomic number and weight.

Alpha particle (*a*-particle): A positively charged nuclear particle consisting of 2 protons and 2 neutrons with a mass of 4 and a charge of +2. It is identical to the nucleus of a helium atom. Its physical properties render it highly ionizing, and therefore it is considered a high LET radiation.

Beta particle: An electron (B-) or positron (B+) ejected from the nucleus of an atom during radioactive decay has mass identical to an electron and a charge of —1 or +1, respectively. B- particles from 32p are used in the treatment of polycythemia vera.

Cobalt-60: A heavy radioactive isotope of cobalt of mass number 60 with a half-life of 5.3 years; emits B- particles and *y*-rays; used in radiation therapy in teletherapy and brachytherapy treatment.

Electromagnetic radiation: Radio waves, x-rays, *y*-rays, etc. radiation having no mass or charge, often spoken of in terms of photon or quanta—a small packet of energy, e.g., visible light, x-rays and *y*-rays.

Gamma (X) rays: Electromagnetic energy generated by an atomic nucleus.

Physical half-life: The time required for one-half the number of atoms of a specific radionuclide to undergo disintegration.

Radium: A radioactive, shiny white, metallic element that resembles barium chemically occurs in combination in minute quantities in minerals, e.g. pitchblende, emits *a*-particles and *y*-rays to form radon and is used chiefly in luminous materials an in the treatment of cancer.

X-rays: Electromagnetic energy produced by electron interactions, as characterized by:

a) rapid deceleration of projectile electrons
b) downward transition of orbital electrons within the tube target

UNITS OF RADIATION MEASUREMENT —

1) Curie (Ci) or Becquerel (Bq) the unit of activity of radioactivity of a nuclide that represents 3.7 x 1010 disintegrations per second. This is based on the rate of decay of 1 gram of radium.

2) Radiation absorbed dose (RAD) or gray: The unit of absorbed dose equal to the radiation necessary to deposit 100 ergs in 1 gram of absorber. The absorbed dose that a certain mass of tissue or an organ receives depends on a number of factors, such as electron density of the material, the attenuation coefficient, the beam energy (or HVL), the field size, and depth of absorber that the beam may have already traversed.

3) Radiation equivalent man (REM) or Sievert: The unit of absorbed dose equivalent which measures the biologic effectiveness of radiation, i.e., the ability to produce a predetermined biological response such as a certain percentage cell killing. It is used

in radiation protection measurements to set safety guidelines in a way that equivocates all types of radiation exposure. It does this by multiplying absorbed dose by a quality factor assigned to a radiation type. X-rays, gamma rays, and beta particles have a quality factory of 1, thermal neutrons a factor of 5, and protons and alpha particles a factor of 20. The SI unit is the Sieverts (Sv), and 1 Sv is equal to 100 rem. In the diagnostic range, 1 R = 1 rad = 1 rem.

4) Roentgen or Coulombs/kilogram: The roentgen is the unit of radiation exposure for X-ray and gamma photons up to 3 MV; an exposure of 1R will yield 2.58 x 10-4 coulombs of charge per kilogram of air. Above 3 MV, it becomes impossible to measure exposure with a conventional exposure chamber.

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[1] Selman, J. *The Fundamentals of X-ray and Radium Physics*. 4th ed. Springfield, IL: Charles C. Thomas, 1970.
[2] Bushong SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis, MO: Mosby, Inc., 2001.

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UNIT NUMBER 2

BASIC X-RAY CIRCUITRY

PREPARED BY: Carolyn J. Frigmanski, M.A., B.S.R.T. (R)

INTRODUCTION

In this unit we will discuss electricity and the various electrical devices we use to create our x-ray circuits. We will also utilize some charts that are helpful for safe operation of our radiographic equipment.

TYPES OF MATERIALS

All matter can be classified according to its ability to allow or inhibit of flow of electrons. The term insulator or non-conductor is used to describe matter that will inhibit the free movement of electrons.[1(p75)] Classic examples of insulators or non-conductors are rubber, glass, and wood. I think all of us realize that the rubber on the tires of our automobiles would prevent us from electrocution if we stay in the car when an electrical wire is down in the streets.

Conductors are materials which allow electrons to flow easily and with little resistance.[1(p75)] The conductors we use most commonly are copper in all of our electrical wiring, aluminum, and water. I think most of us realize that it is not a wise idea to have electric radios and telephones in the proximity of our bathtubs. When the bathtub is full and you are submerged in it, the risk of electrocution is possible if the electric radio or telephone should accidentally fall into the water because of the conductive nature of water.

The last category of materials used in the flow of electrons is semi-conductors. Semi-conductors allow electrons to flow only under certain conditions and prohibit electrons from flowing under certain other conditions.[1(p75)] This principle of semi-conductivity is utilized in solid state rectification systems for our home appliances, in addition, to our radiographic equipment.

ELECTRIFICATION

The process of electrification occurs when an object becomes charged by the removal or addition of electrons.[1(p72)] You may recall from Unit 1 that when an atom looses an electron it becomes positively charged and when an atom gains an electron, it becomes negatively charged. This transition of electrons can occur in three methods.

In the method of contact, a connection must be made that will allow the electrons to flow easily. If the electric radio or telephone makes contact with the bath water, electrons will flow without any difficulty. The second method of electrification occurs in the process of friction. Friction results by the build up of electrons by rubbing objects together. I am sure all of us have had an opportunity to rub an air filled balloon on our hair and then place it next to a wall where it adheres to the surface for a short time. I am sure some of the older radiographers reading this material can relate to the process of rubbing your socks on shag carpeting (when it was fashionable) to provide a "poke" to a sibling or household pet. In radiography, friction most occurs when sliding cassettes on darkroom counters. The electron buildup from the friction may cause a "spark" which creates density on our finished images. The last method of electrification is called induction. This method involves having an object that has a charge surrounding it in the proximity of another object that possesses no charge. The uncharged object will retain a charge as long as it stays in the electrical field of the charged object. We use the principle of induction when operating various switches and devices in our radiographic equipment

The direction of the flow of electricity has been confusing over time. Physicists describe the direction of "conventional current" in a conductor as the direction of the flow of positive charges.[2(p64)] In other words, electric current flows from the positive end of a wire to the negative end. We now know and describe electron flow as flowing from negative to the positive end of a conductor.

LAWS OF ELECTROSTATICS

The laws of electrostatics have a close correlation to the laws of magnetism. One of the fundamental law states that opposite electrostatic fields will attract and like electrostatic fields will repel.[1(p73)] When a negative electrostatic field is brought in proximity to another negatively charged object, the act of repulsion occurs. By the same token, when a negative charged object is placed in the electrostatic field of a positively charged object, attraction occurs.

Coulomb's Law is part of the law of electrostatics. Coulomb's Law describes the fact that an electrostatic force is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.[1(p74)] To understand this law it is essential to understand the term Coulomb. Electric charges are measured in Coulombs. A Coulomb is essentially a certain number of electrons for a negative charge or protons for a positive charge. A Coulomb is the amount of charge on 6.3×10^{18} electrons or in conventional notation represent 6,242,500,000,000,000,000 electrons.[1(p73)] Therefore, if the electrostatic force of one object was 2 Coulombs and the electrostatic force of a second object was 5 Coulombs, the total electrostatic force field is multiplied and the resultant force field would be equivalent to 10 Coulombs. If we use the same electrostatic fields of 2 Coulombs on one object and 5 Coulombs on another and separate them twice the amount of the distance used in measuring their charge, we would find that the charges have diminished to one-fourth of the original combined electrostatic field. The resultant charge would be equal to 2.5 Coulombs.

The last of the electrostatic laws is electric charges are concentrated along the sharpest curvature of a surface.[1(p74)] If we use the example of an egg shaped object, we would find that there would be a greater concentration of electrons at the pointed portion of the egg than at the broader end. This occurs because there is less surface area for the electrons to reside in at the pointed portion of the egg when compared to the surface area of the broader portion of the egg.

UNITS OF ELECTRICITY

The unit of current is the ampere.[1(p78)] One amp of electricity will flow past the point in a conductor when one Coulomb of charge moves by that point each second.

1 amp = 1 Coulomb/second

It is a quantity of electrons flowing per second in a circuit or charged object.

A volt is a unit of electrical potential or pressure.[1(p78)] A synonym is EMF or electromotive force. The EMF of the source is not really a force, but it is the potential difference between charges. The value of the potential difference between objects is more appropriately described as a volt.

Within any electrical system resistance is inherent because of the material itself. The unit of electrical resistance is described as the Ohm and is influenced by four factors.[2(p67)]

1. Temperature: as the temperature rises, the resistance increases.
2. Cross-sectional area: the larger the diameter, the less resistance to electron flow.
3. Length: the longer the length of the conductor, the greater the resistance.
4. Material: selecting materials that are conductors will minimize the degree of inherent resistance to electron flow.

Because of the inter-relationship between Amps, Volts and Ohms, a law was proposed by Georges Ohm. He discovered that the voltage across the total circuit or any portion of this circuit is equal to the current times the resistance.

The work performed in moving a charge between two points in an electric field is know as potential difference between these points. In other words, potential difference describes the electric field in terms of energy and work.

Ohm's Law: Volts (V) = Amps (current) x Ohms (resistance)[1(p78)]

A circuit is simply defined as a closed path for electrons to flow.[1(p77)] It usually contains a source of potential difference, one or more resistances, and may include other devices as well.

The unit of electric power is called Watts.[1(p80)]

Watts: Amps x Volts

A Watt is also described as a Joule per second. Since the Watt is a very small unit, the kilowatt is most often utilized. If you look at your electricity bills, you will see that the amount of electricity consumed in your house is measured in kilowatt-hours.

TYPES OF ELECTRICITY

Direct current allows electrons to flow in one direction along the conductor.[1(p80)] When we close the circuit, electrons will flow. When we open the circuit, electrons will cease to flow because the continuity of the pathway has been interrupted. When direct is flowing, the voltage reaches a peak or maximum and stays constant at that plateau.

The second form of electricity is called alternating current. Alternating current allows electrons to oscillate back and forth along the conductor.[1(p80)] These electrons also change their polarity. When we diagram alternating current, we see one-half of the cycle as positive and the other half of the cycle as negative. Each half of the cycle is described as an alternation. Therefore, two alternations equals one cycle. The number of cycles of electricity flowing per second corresponds to the frequency in the circuit. In the United States we use a 60 cycle frequency. We have 60 cycles of electricity flowing per second and each alternation or each half of the cycle represents 1/120 of a second. Electrons will flow in one direction for 1/120 of a second and alternate their direction of flow for the next 1/120 of a second. When we close the circuit, the voltage has to build to the peak and then it drops back down to zero at the conclusion of its 1/120 second. The next alternation has to "grow" to the peak and then it also drops down to the zero voltage when its alternation time is over. When current is closed the electrons flow and the beginning of the cycle is called the "make" position. When the current is opened, the electrons flow and the ending of the cycle is called the "break" position.

Alternating current is the preferred current used in our x-ray generating equipment. It is necessary to operate our transformers and we experience less loss over greater distances.

INCOMING VOLTAGE

We have an electrical or nuclear power plant producing huge quantities of electricity in all of our cities. However, these power plants need to distribute their electrical energy to various neighborhoods in the community. When you are driving your automobile, you may notice that there are particular telephone (utility) poles that contain a large gray canister near the cross-arms. These gray canisters are referred to as pole transformers that distribute the electricity generated from the plant to the respective homes in the neighborhood. When an automobile accident occurs and a telephone (utility) pole containing the transformer is damaged, the neighborhood may be considered a "black-out". There is no electricity in the neighborhood and yet houses located across the street that are furnished with electricity from a different pole transformer remain lit.

Because we are able to generate large amounts of electricity, it has been necessary to develop a three-wire system. Most of us have appliances that have plugs with three prongs. The two flat prongs are related to the two wires carrying electricity within the rubber insulation layer and are "hot". The rounded prong is also a wire that is used to serve as a "ground". This ground prevents the overloading of the circuit from damage and fire hazards.

It is important to note that our incoming voltage is not always consistent. Because of this problem, it has been necessary to develop a device called a Line Voltage Compensator. This device compensates for fluctuations of incoming voltage. When the incoming voltage is less than expected it is called a line drop. If the voltage exceeds the expected amount, it is called a line surge. If we did not control these fluctuations in incoming voltage, we would not be able to operate devices in a consistent manner to provide consistent results.

ELECTRIC CIRCUITS

Since the electrons flow along the outer surface of a wire, we can create various configurations of pathways. We refer to these as circuits.

A circuit that has only one current path is known as a series circuit.[1(p78)] A series circuit has all elements connected in a line along the same conductor. If the path of electron flow is interrupted, the entire circuit ceases to operate. This was the circuit utilized in Christmas tree lights years ago. If one bulb burned out, the entire string of lights remained unlit.

A circuit, with more than one current path is called a parallel circuit. Parallel circuits have elements that bridge the conductor rather than lie in a line.[1(p78)] Some complex circuits consist of both series and parallel branches. If a section of the parallel circuit is interrupted, the result will not be the failure of the entire circuit to operate. For example, if you burn out a light bulb in your home, other appliances are able to operate without any difficulty.

SHOCK PROTECTION

The shock from 120 volt or a 220 volt line is dangerous and can be fatal to human beings. There are essentially two lines of defense against shock. The first line of defense is to keep the electricity in the wires and the second is to arrange the circuits so that any escaping electricity will do no harm. When a substantial amount of current passes through the body, it causes spastic contraction of muscles. Since the heart is a large muscle, it can cause fibrillation and cardiac arrest. Most situations involving the electrocution of human beings results from wet hands or feet touching a high-potential wire. Rubber shoes insulate the body from ground and prevent the formation of a complete circuit to prevent electrocution. Good insulation is necessary to keep the risk of electrocution at a minimum. Insulation on wiring may be intact when it is first installed but then crack or wear off with age. This "fracture" of the insulating layer may cause electricity to flow out of the circuit and thereby create risk for electrocution.

The key protection in guarding against shock is grounding.[2(p427)] Grounding allows the circuit to be planned in such a way that a failure of the insulation will result in a direct low resistance path from the high potential of the voltage to the earth. All established electric codes for installation of electrical devices and wiring in private and public dwellings require careful grounding. Connections from one wire to another must be enclosed in a metal box. Every switch, outlet and lamp connection must be surrounded by metal. All the metal boxes should be connected to each other by grounding wires in the cables that run through the walls of your home. Some state regulations require that cables be enclosed in metal sheathing. This electrical system style is grounded either by connecting it to the water pipe or to a separate rod driven ten feet into the ground. Modern installations require three-prong outlets.

MAGNETISM

Magnetism was identified in ancient times when it was observed that certain rocks, called lode stones, attracted iron. Lodestone is a natural magnet. It was also discovered that when pieces of iron were rubbed with lodestones, the iron became magnetized. The Chinese in ancient times magnetized a very thin piece of iron and floated it on water. Since one end of the magnet always pointed to the north, the Chinese were able to use these devices as compasses to navigate large bodies of water.

The phenomenon of magnetism is associated with all substances. In an atom, the electric charges or electrons move in a circle about the nucleus. Each electron spins on its own axis. This spinning forms an additional magnetic field within the element.[1(p84)] In atoms of most materials, the magnetic fields produced by these spinning electrons cancel one another out by rotating in opposite directions. A material that is a magnet has electrons with unbalanced magnetic fields. Thus, the atom acts as if it were a magnet. These atoms tend to align themselves to form small magnetic areas within the material. These areas are called magnetic domains.[1(p84)] When the north and south poles of the various domains are arranged randomly, the piece of metal is not magnetized. When the north and south poles of the various domains are aligned appropriately, magnetism exists.

GENERAL PROPERTIES OF MAGNETS

Magnets have north and south poles named by the way they orient themselves in the Earth's magnetic field.[1(p88)] The end of the magnet that points northward is the North Pole of the magnet and the end of the magnet that points southward is the South Pole. Unlike electric charges, single magnetic poles have not been discovered. A North Pole is found in conjunction with a South Pole.

When two magnets are brought near one another, it has been observed that like poles will repel and unlike poles attract.[1(p88)] This property is similar to that of electric charges. If a metal is brought in the vicinity of a magnet, the metal itself will become magnetized. If the metal retains its magnetic properties after the original magnet has been removed, it is call a permanent magnet.[1(p89)] If the magnet does not retain its magnetic properties, it is considered a temporary magnet. Alnico, an alloy made of aluminum, nickel and cobalt, makes good permanent magnets. Soft iron produces excellent temporary magnets.

The existence of magnetic forces is explained by the presence of a magnetic field. The magnetic field lines or lines of force are used to map out the magnetic configuration. Lines of force may also be referred to as flux lines. Lines of force are closer together when the force is greater. At greater distances from the charge, the lines separate and the force diminishes.

The Earth has a magnetic field that is easy to plot. If a permanent magnet is suspended and free to rotate, one end of the magnetic needle will point north. The compass actually points to the magnetic north that is located at a point 70° north latitude on the East Coast of Greenland. Magnetic field lines enter the earth at this location. The location in Greenland is the South Pole of the earth. The Earth's magnetic field is generated from the core. The core of the earth is a solid mass of iron and nickel that is surrounded by hot liquid metal more than a thousand miles deep. Because the earth is hottest at its center, there are convection currents in the liquid metal. The rotation of the earth distorts the currents so that they flow around the earth. A feedback mechanism is set in which the small convection currents produce magnetic fields. These magnetic fields amplify the current. As the current increases, the magnetic field increases. This theory has provided an explanation to the fact that every few hundred thousand years, the polarity of the Earth's field reverses.

ELECTROMAGNETISM

In 1920 a Danish physicist names Hans Oersted discovered that a wire carrying a current produced a magnetic field. This phenomenon was demonstrated visually in Davy's experiment. A hole was placed in the center of a piece of cardboard and a wire carrying current was inserted through the opening. Iron filings were then scattered randomly on the sheet of cardboard. When the conductor was connected to an electric current, the iron filings aligned themselves in concentric circles around the conductor on the cardboard that graphically represented the lines of force of the magnetic field.

A solenoid is a simple device that consists of a coil of wire carrying current.[1(p93)] If a soft iron core is inserted in the coil of wire of the solenoid, an electromagnet is created. The electromagnet will only be magnetized when electricity is flowing. The classic example of an electromagnet is the crane that is utilized in car junkyards. The cable of the crane's wire has a large metal disc on the end. When a car needs to be relocated in the junkyard, the crane swivels this large metal disc to the roof of the car. When the electricity is on, the metallic disc becomes an electromagnet and attaches to the car. The electromagnetic disc and car are then moved collectively to the new location. When the electricity is switched off, the electromagnet ceases to exist and the car drops to its new location. We use electromagnets in switches and in interlocking doors for our radiology equipment.

METHODS OF INDUCTION

We can induce voltage in a conductor by placing a stationary wire in a moving magnetic field by utilizing a stationary magnet with a moving conductor or by utilizing a stationary conductor in a magnetic field that has varying strength.[1(p96)] When a conductor carries electricity, a magnetic field will be associated with the conductor. If the conductor is utilizing alternating current, the magnetic field expands and contracts every 1/120 of a second around the conductor, in addition to changing its polarity.

When the conductor is attached to a source of electricity, the electricity is called applied EMF.[2(p99)] When the applied EMF is flowing through the conductor, the associated magnetic lines of force will expand and extract around the conductor. When the lines of force cut the conductor, an opposing EMF or voltage will be created to flow against the applied voltage. This is referred to as back EMF. This whole concept is described as self-induction. In other words, the conductor itself induces back EMF by the very nature of its expanding and contracting magnetic field.

The second method of induction is called mutual. Mutual induction requires two conductors lying in proximity, but not touching each other. The primary conductor, usually in the form of a coil, is connected to current.[1(p97)] The secondary conductor or coil has no current flowing in it. When the electric current is flowing in the primary coil, an expanding and contracting magnetic field exists. If the secondary coil is cut by the magnetic lines of force, a voltage will be produced. This principle is utilized in our transformers. It explains how we are capable of producing the desired kilovoltage when we perform a radiographic examination. For example, if I am doing a portable exam, I may plug my portable into an outlet that carries 120 volts of electricity. Yet I will select 70 kV or 70,000 volts of electricity on the control panel of the portable. The question is where did the kV come from? The answer is the incoming 120 volts of electricity was applied to a transformer consisting of a primary and secondary coil. If the number of coils in the secondary are greater than the number of coils in the primary, the voltage will be "stepped up" or increased correspondingly. Therefore, if I had one coil on the primary side for each volt of electricity and 1000 coils on the secondary side, I could create a ratio of 1:1000 that would coincide to one volt on the primary side would create 1000 volts on the secondary side. In that manner I would be able to change each volt into one kilovolt or kV.

GENERATORS AND MOTORS

A generator is an electrical device that lets us convert mechanical energy into electrical energy. The generator consists of a moving armature in a stationary magnetic field.[1(p97)] When the armature rotates in the magnetic field, the lines of force are cut and a voltage is induced. Some of you may remember when we had generator lights on our bicycle handlebars. A small canister containing the armature and magnetic field was attached to the rear bike frame so that a knob-like device rotated when the rear bicycle wheel rotated. A wire then extended from the generator canister along the frame of the bicycle up to the headlight that was mounted on the handlebars. The faster you peddled the bicycle, the more revolutions the armature experienced and the more lines of force cut in the stationary magnetic field. This caused greater voltage and allowed the bicycle light to burn brightly. However, when you slowed down or used your brakes on the bicycle, the light diminished in its intensity because the armature was not rotating as quickly and fewer lines of force were cut. This created a decrease in voltage and the headlight was less bright or out completely.

A motor converts electrical energy into mechanical energy and utilizes the same component parts.[1(p98)] There is an armature and a magnetic field. The only difference with the armature in the motor when compared to the armature in the generator is the fact that the motor armature has current flowing in it. Whenever we use a device with motor, you need to plug it in and turn it on to operate it. The motor contains a fixed magnetic field. When you turn on the current, the armature with current in it has its own magnetic field. If the armature with its own magnetic field is inserted in the stationary magnetic field with the lines of force in the same direction, the armature will be thrust out of the stationary magnetic field by the act of repulsion. This can be simply demonstrated with an electric fan. When you plug the electric fan in and turn it on, the thrusting motion of the magnetic field causes the armature to rotate the fan blades.

AUTOTRANSFORMER

An autotransformer has both a primary and secondary coil that are wound together as a single coil with tappets or contacts drawn from the center coil.[1(p100)] The autotransformer operates on the principle of self-induction and allows us to tap or select predetermined amount of voltage to be converted to kilovoltage in the circuit at the location of the transformer.

TRANSFORMERS

Transformers are electrical devices that allow us to change and control voltage by the process of mutual induction.[1(p98)] The amount of voltage produced and controlled is in proportion to the number of primary and secondary coils. The primary circuit of the x-ray machine originates from the source of electricity to the primary coil of the step-up transformer. Its primary function is to create high voltage. The secondary circuit of the x-ray equipment is connected from the secondary coil of the step-up transformer to the x-ray tube itself.

There are two laws for transformer operation. Whenever voltage is increased, the number of turns in the primary must be increased proportionately. See the formula listed below:[1(p99)]

$$\frac{\text{Volts in the secondary coil}}{\text{Volts in the primary coil}} = \frac{\text{number of turns in secondary coil}}{\text{number of turns in the primary coil}}$$

We are able to calculate the amount of voltage that will be produced utilizing this formula. However, because of Ohm's Law, we realize that as the voltage goes up, amperage will go down.[1(p99)]

$$\frac{\text{Amps in the secondary coil}}{\text{Amps in the primary coil}} = \frac{\text{number of volts in the primary coil}}{\text{number of volts in the secondary coil}}$$

There are two types of transformers. A step-up transformer has more turns in the secondary coil than in the primary and allows us to create kilovoltage in out circuits.[1(p99)] A step-down transformer has more turns in the primary coil and less in the secondary coil. The step-down transformer is located in our filament circuit that operates on 10-15 amps of electricity. It is important to reduce the incoming voltage to a smaller amount so that the x-ray tube filament can be heated appropriately for thermionic emission.

There are four construction types for transformers. A simple air core transformer has a primary coil of wire and a secondary coil of wire.[2(p122)] This is very inefficient because the lines of force generated in the coils of wire are lost in space because there is not a continuous path for them to follow.

An open core transformer is the air type with a soft iron core inserted in each coil.[2(p125)] This allows us to increase the voltage that can be produced in the secondary coil because we are increasing the number of lines of force by magnetizing the soft iron cores. However, since the soft iron cores are open at the ends, the lines of force are dissipated in space and nonproductive.

The third type of transformer is the closed core transformer in which the ends of the soft iron cores are connected together.[1(p100)] We get a characteristic donut-shaped configuration with the primary coil on one portion of the donut and the secondary coil on the other side of the donut. In this manner we have been able to utilize the lines of force that escaped at the ends of the open core and increased the efficiency in voltage production.

The fourth and most efficient, expensive transformer is the shell-type.[1(p100)] It consists of a series of laminated "double donut" metal pieces that have the primary and secondary coils wound on the central portion. These two coils of wire are highly insulated from each other. Now the lines of force produced in the primary coil and those in the secondary coil can be completely utilized to improve the overall operation and capacity of voltage generation.

EXPOSURE TIMERS

There are five exposure timers on the market today. Exposure timers break the high-voltage across the tube to control the length of x-ray exposure.[1(pp110-111)]

Electronic timers allow a wide range of time intervals to be selected and are accurate to intervals as small as 1 millisecond. They are used in most radiographic equipment today and are especially suitable for angiography equipment

Photo-timers measure the quantity of radiation reaching the image receptor by automatically terminating the exposure when sufficient radiation to provide the required optical density has been satisfied.

Photomultiplier photo-timers view a fluorescent screen and convert the light from it into an electric charge. The intensity of the fluorescence is directly proportional to the intensity of the incident radiation. The exposure is terminated when a pre-selected charge has been reached by the photo-multiplier. The charge corresponds to the desired film density for the radiographic examination based on radiologist preference.

Ionization chamber auto-timers contain two electrodes that are charged. As radiation moves through the chamber, the air molecules are ionized and a current is produced. When the described current has satisfied the auto-timer, exposure will cease.

Solid state auto-timers utilize a type of photocell similar in phototiming or AEC (Automatic Exposure Control).

EXPOSURE SWITCHING

Exposure switching turns the high voltage applied to the x-ray tube on and off. Primary switching is located in the low voltage primary circuit in general purpose three phase x-ray generating units. There are three types: electromechanical contractors, thyratrons, and solid-state-silicon-controlled rectifiers.

Secondary switching is used in units designed for rapid, repetitive exposures or where extremely short exposure times are needed. The switches are located in the high voltage secondary circuit of angiographic x-ray equipment. There are two types: Triode vacuum tubes and grid-controlled x-ray tubes.

FALLING LOAD GENERATORS

Falling load generators produce an x-ray exposure with the shortest possible exposure time by operating the x-ray tube at its maximum kilowatt rating during the entire exposure.[1(p249)] It automatically sets the highest mA and shortest time for a constant kVp. It is used in automatic exposure generators.

HIGH VOLTAGE CIRCUIT

The step-up transformer increases voltage potential across the x-ray tube.[1(p111)] It controls kVp. A mAs meter is grounded in the midpoint of the secondary coil of the step up transformer.

RECTIFICATION AND ITS TYPES

The word "rectify" means simply the change. Rectification is the process of converting alternating current to direct pulsating current.[1(p113)] This conversion is feasible by utilizing rectification devices. In self-rectification, the alternating current flows for 1/120 of a second from the secondary coil of the high-tension transformer to the cathode of the x-ray tube. X-rays are made at the anode. The electricity continues to the secondary coil. When the next alternation occurs, the electrons now reverse polarity and direction and follow along the circuit to the anode of the x-ray tube. Since no space charge exists, the current is stopped. In other words, the anode of the x-ray tube rectifies the circuit. This is a very inefficient system since only 50% of the alternating current sine wave can be used productively. It impresses a great deal of wear and tear on the anode of the x-ray tube.[1(p115)]

To eliminate this risk, a valve tube or kenetron was designed. It is a smaller thermionic diode tube that contains both a cathode and an anode. It is different in construction than an x-ray tube because the cathode lies horizontally and is enclosed by a cylindrical shaped anode. This keeps the electrons confined to a small area to follow the circuit as constructed. One or two valve tubes can be inserted in the circuit. When the circuit is closed, the electricity will flow from the secondary coil of the step-up transformer through the cathode and anode of the valve tube to the cathode and anode of the x-ray tube. If a second valve tube is installed, it will pass through the cathode and anode of the second valve tube on its return to the secondary coil of the step-up transformer. When the electricity changes polarity, the electrons will go to the anode of the valve tube and be stopped at this point. This minimizes the possible risk of damage to the x-ray tube anode. This is considered half-wave rectification because only 50% or one alternation of the sine wave is utilized.[1(p115)]

With the introduction of four valve tubes, the alternations of the sine wave can be completely utilized, thereby increasing the efficiency of the x-ray generating equipment. The valve tubes must be located in proper relationship to the corresponding alternations. If three-phase equipment is utilized, three sine waves of alternating current must flow in the circuit. Four valve tubes are utilized for each sine wave. Three phase equipment will require 12 valve tubes. As our technology has improved over time, these glass envelope valve tubes have been replaced by solid state rectifiers. Solid state rectifiers perform the same function with the movement of electrons in the semi-conductive material of the rectifier.[1(p115)]

PROPERTIES OF TUNGSTEN

Tungsten is utilized in the filament of the x-ray tube and the target on the anode.[1(p129)] Tungsten was selected because it has the high atomic number of 74 that allows a great number of electrons to be available in the space charge at the cathode. A great number of electrons will be available for interaction at the anode when the space charge electrons are driven a short distance to interact with them. Tungsten also has high thermal conductivity that allows it to dissipate the excessive heat produced in the x-ray tube very quickly. Tungsten has a high melting point of 3,370°C that accommodates the temperature range when x-rays are generated in the x-ray tube. W is the chemical abbreviation for Tungsten.

EXTERNAL STRUCTURES OF X-RAY TUBES

A ceiling or floor to ceiling support system is required.[1(p123)] The external structure of the x-ray tube consists of a protective housing that contains oil for electrical insulation and thermal cooling. A medical physicist must check for leakage radiation-x-rays that may escape through the protective housing. They contribute nothing in the way of diagnostic information and result in unnecessary exposure to patient and radiographer.

Inherent filtration and properly designed protective housing reduces the level of leakage radiation to less than 100mR/hr at 1m when operated at maximum conditions.[1(p124)]

High voltage cables contain a grounding sheath of wires to ground the x-ray tube and convert low voltage into a kilovoltage of the proper waveform. Oil serves as electrical insulator and thermal cushion. A fan is used for cooling. A glass Pyrex envelope enclosure contains the working parts of the x-ray tube.[1(p124)] The glass enclosure is as perfect a vacuum as possible. The tube is degassed during the manufacturing stage to expel air and other gases that may have been trapped in the glass or metal parts. The vacuum offers an unobstructed path for the electron stream and prevents burning out of the x-ray tube. The window is a thin section of glass envelope through which the useful beam emerges.

INTERNAL STRUCTURES OF X-RAY TUBES

The cathode is a negative terminal in which a small coil of tungsten wire has been mounted on two stout wires that support it and also carry electric current.[1(p125)] The filament of tungsten or thoriated W may have a dual focus or double filament. Two filaments are mounted side by side. The filaments usually differ in size and produce focal spots of two different sizes on the target; a.k.a. double focus tubes. Only one filament is activated for a given exposure. Thermionic emission is the emission of electrons from a heated source known as the cathode. A "space charge" is the collection of electrons "boiled off" at the heated cathode. mA can be increased only by increasing the filament current and temperature.

The focusing cup keeps the space charge electrons confined to a small area until the exposure switch is activated and kilovoltage is applied.[1(p126)]

The anode is the positively charged terminal.[1(p128)] Tungsten is used for the target because of its high atomic number and high melting point. The line focus principle allows x-rays to be produced on a fairly large area on the anode while causing the film to perceive that the x-rays were produced from a small area. The actual focal spot is the area on the anode where x-rays are produced.

The effective/apparent/projected focal spot represents the x-rays that are emitted and represents how the film perceives it.

A stationary anode is used in dental radiography, some portable machines and other special purpose units in which high tube current and power are not required.[1(p128)] These are usually made of tungsten and copper.

A rotating tube is used in general purpose x-ray tubes.[1(p128)] It is capable of producing high-intensity x-rays in a short time. It rotates at 3300-3600 RPM for diagnostic equipment. High speed rotating anodes may operate at 10,000 RPM for special procedures equipment. The rotating anode is usually constructed of molybdenum and tungsten-rhenium alloys with a target of W or rhenium coated W.

The filament circuit operates on low mA and voltage.[1(pp126-127)] Its purpose is to increase current to the filament. Transformer type is a step-down transformer. It controls mA by increasing current thereby increasing electrons released by thermionic emission from filament

COMPONENTS OF THE X-RAY BEAM

The intensity of the x-ray beam represents the number of photons in the beam multiplied by the energy of each photon. As mA increases, intensity increases because of the increase in quantity.[1(p149)] The higher the atomic number of the target atoms, the greater will be the efficiency of the production of x-rays. An increase in kVp increases exposure rate because electrons in the x-ray tube are accelerated to produce more photons per second at the target. The number of x-rays produced depends on the number of electrons that strike the target of the x-ray tube. Increasing mA will increase quantity, and the spectrum will increase at all energies. Ninety-nine percent (99%) of the kinetic energy of the projectile electrons is converted to heat with less than 1% converted to the production of x-rays.

Characteristic radiation is produced when x-rays ionize electrons in the inner shells of the tungsten target atoms.[1(p143)] The x-ray photon has energy equal to the difference in the binding energies of the orbital electrons. The characteristics of the radiation that is produced will depend on the binding energy of the target material. The electron energy requirement for a K- shell electron of tungsten has to exceed 70 keV. When the tungsten atoms become ionized, other electrons from the shells must transfer into the vacancies. As the electrons descend from outer to inner shells, characteristic radiation is emitted relative to the shell of origin. These characteristic x-rays possess discrete energies and constitute approximately 10% of the primary beam when tube potentials are selected in the 80-100 kVp range.

Bremsstrahlung is the German word for "braking". As the electrons travel a short distance from the negative cathode to the positive anode in the x-ray tube, their negative charge interacts with the negative electrostatic field of the bound atoms.[1(p145)] Deceleration of the projectile electrons from the cathode is converted to x-rays. It must be remembered that the electrons from the cathode do not strike the target with the same amount of energy.

FACTORS AFFECTING X-RAY EMISSION

Increasing mA increases the number of electrons which thereby increases the number of x-rays. Increasing the kVp increases the penetration of the beam which thereby increases the number of x-rays that will reach the film. Increasing the filter thickness or atomic number increases the hardness of the beam, but reduces quantity.[1(p150)] Increasing the atomic number increases the number of electrons available for interaction that thereby increases the number of x-rays. Using three-phase equipment provides a 12% increase in kVp or almost a doubling of mAs when compared to single phase equipment.[1(p152)]

TUBE RATING AND ANODE COOLING CHARTS

It is important for radiographers to use the right chart for the right room for the right purpose. Tube rating charts reflect the combination of mA, time and kVp that may be used safely.[1(p137)] In the construction of most charts, the time is on the horizontal axis; kVp is on a vertical axis; and the mA is represented by a curvilinear line within the graph. Whenever a combination of technical factors intersects below the selected mA line, the combination is safe. If the combination of technical factors intersects on or above the mA line, it is considered unsafe. Usually the equipment will have an overload warning on it. The equipment will not let the radiographer continue making the preliminary exposure combinations.

Anode cooling charts provide information for radiographers relative to the heat dissipation rate when exposures have been made on the x-ray tube.[1(p138)] To utilize the anode cooling chart, it is important to first calculate the heat units that are produced with any combination of technical factors. A synopsized chart is provided below.

Heat Unit calculations for-single-phase = mA x second x kVp
Heat Unit calculations for-3 phase 12 pulse = mA x second x kVp x 1.35
Heat Unit calculations for-3 phase 6 pulse = mA x second x kVp x 1.41

Heat units indicate the thermal capacity of the anode. When the anode gets extremely hot, cooling occurs most rapidly. Let us use the following examples in calculating heat units.

For a single-phase room, an exposure combination was selected of 300 mA 1/10 second at 80 kVp. Calculate the heat units for this exposure.

300 x 1/10 x 80 = 2,400 Heat Units

For a 3-phase 6-pulse 500 room, mA at 1/5 second at 80 kVp was used. Calculate the heat units for this exposure.

500 x 1/5 x 80 x 1.35 = 10,800 Heat Units

For a 3-phase 12-pulse room, 1000 mA was used at 0.3 seconds at 70 kVp. Calculate the heat units for this exposure.

$$1000 \times 0.3 \times 70 \times 1.41 = 29{,}610 \text{ Heat Units}$$

Once we have determined the number of heat units produced in the exposure, we can refer to the anode cooling chart to determine how long it will take the anode to cool down to zero or to dissipate a certain volume of heat units in a predetermined time. Let's use the three exposures we just calculated for heat units and apply them an angiographic runoff with 20 exposures for each one. We simply multiple the units for each exposure times the total volume and then cross reference this heat unit amount with the heat units identified on the vertical axis of the anode cooling chart. When we draw a perpendicular from that heat unit amount on the curve to the horizontal axis, we can determine the exact number of minutes required for cooling.

PROLONGING TUBE LIFE

To prevent pitting/cracking, the maximum radiographic technical factors should NOT be applied to a "cold" tube. Radiographers must follow the recommended warm procedure. Vaporization is the melting of the filament and plating on the glass envelope. It is the most common cause of tube failure. Long exposure times and excessive heating can damage bearings in the rotor assemble.

COMPONENTS OF THE OPERATOR'S CONSOLE

Medical radiographers are able to adapt to a wide variety of x-ray generating equipment because of common controls on the operator's console.

The main power control lets us energize the x-ray equipment by turning on the source electricity. The mA or combined mAs selections are used to produce the desired density on the radiographic examination being performed.[1(p107)] The kilovoltage (kVp) selections allow us to select the optimum kilovoltage to penetrate the anatomic organ under examination and provide the desired scale of contrast. Minor kilovoltage can be altered in increments of 2 kV and major kVp selections indicate the kilovoltage can be increased or decreased in increments of 10. The operator console will also have a table or wall bucky button selection so that you can utilize the grid for anatomic body parts measuring over 10-12 cm in thickness. When the bucky button is off, the grid is no longer activated. Tabletop examinations do not require a grid and are performed on small body parts such as fingers, toes, etc. The exposure switch on the console should be attached directly to the operator console or may be controlled by a remote switch. The exposure switch should not allow the operator the capacity to extend beyond the protective barrier of the control booth. Focal spot selections are usually indicated as small or large. In some instances the focal spot will be linked to the mA selection. mA selections under 100 will utilize a small focal spot and mA selections over 100 will utilize a large focal spot. The ballistics mAs meter moves during the length of exposure and registers the selected mA. It is important to watch the ballistics mAs meter during every exposure. If the resultant images become inconsistent, the ballistics mAs meter can provide some suggestion of the problem. For example, if the needle on the ballistics mAs meter does not stay at the selected mA for the length of time you have selected, it indicates a timer problem. If the needle on the ballistics mAs meter stays active for the length of time selected but does not reach the desired mA or does not stay at the selected mA station long enough, it indicates that a problem may exist with the rectification system or x-ray tube itself. Automatic exposure control (AEC) if applicable, has some distinct advantages in providing consistently good exposures on patients with hidden pathologies if positioning is appropriate. If the radiographer does not position the central ray over the anatomy of interest, the phototimer or automatic exposure mechanism will not terminate the exposure appropriately. Automatic exposure control increases the exactness of radiographer's positioning skills, but may decrease their appreciation of radiation dose since they are not quantifying it in a manual technique method. It is not a good idea for medical radiographers to become dependant on automatic exposure controls. If they relocate to another place of employment, they may not have the capabilities of automatic exposure control and the radiographer will or may have some difficulty in adapting manual techniques. The control panel will also have an overload button or indicator of some type so that radiographers cannot exceed the acceptable tube ratings of mA, time, and kV for the x-ray tube that is installed in the equipment.

This concludes unit 2. Please proceed to the unit questions and complete the required personal data.

Some Important Terms and/or Concepts in Unit 2

Insulators or non-conductors are materials that will inhibit the free movement of electrons

Conductors are materials that allow electrons to flow easily and with little resistance.

Semi-conductors allow electrons to flow only under certain conditions and prohibit electrons from flowing under certain other conditions.

The process of electrification occurs when an object becomes charged by the removal or addition of electrons.

The unit of current is the ampere.

A volt is a unit of electrical potential or pressure.

An ohm is a unit of electrical resistance.

Direct current allows electrons to flow in one direction along the conductor.

Alternating current allows electrons to oscillate back and forth along the conductor. These electrons change their polarity.

A three-wire system includes two flat prongs are related to the two wires carrying electricity within the rubber insulation layer and are "hot". The rounded prong is used to serve as a "ground".

A circuit that has only one current path is known as a series circuit.

A circuit with more than one current path is called a parallel circuit.

The key protection in guarding against shock is grounding.

Magnets have north and south poles named by the way they orient themselves in the Earth's magnetic field.

We can induce voltage in a conductor by placing a stationary wire in a moving magnetic field; by utilizing a stationary magnet with a moving conductor; or by utilizing a stationary conductor in a magnetic field that has varying strength.

A generator is an electrical device that converts mechanical energy into electrical energy.
A motor converts electrical energy into mechanical energy.

An autotransformer has both a primary and secondary coil that are wound together as a single coil with tappets or contacts drawn from the center coil to allow voltage to be selected and converted to kilovoltage at the location of the step up transformer.

Transformers are electrical devices that allow us to change and control voltage by the process of mutual induction.

A step-up transformer has more turns in the secondary coil than in the primary and allows us to create kilovoltage in out circuits. A step-down transformer has more turns in the primary coil and less in the secondary coil. The step-down transformer is located in our filament circuit because it operates on 3-5 amps and 10-15 volts of electricity.

Exposure timers break the high-voltage across the tube to control the length of x-ray exposure.

Exposure switching turns the high voltage applied to the x-ray tube on and off.

Falling load generators produce an x-ray exposure with the shortest possible exposure time by operating the x-ray tube at its maximum kilowatt rating during the entire exposure.

A mAs meter is grounded in the midpoint of the secondary coil of the step up transformer to prevent overload.

Rectification is the process of converting alternating current to direct pulsating current.

Tungsten is utilized in the filament of the x-ray tube and in the target on the anode.

The cathode is a negative terminal composed of a small coil of tungsten wire has been mounted on two stout wires to support it.

Thermionic emission is the emission of electrons from a heated source known as the cathode in the x-ray tube.

The focusing cup keeps the space charge electrons confined to a small area until the exposure switch is activated and kilovoltage is applied.

The anode is the positively charged terminal. Tungsten is used for the target because of its high atomic number and high melting point.

Characteristic radiation is produced when x-rays ionize electrons in the inner shells of the tungsten target atoms.

Bremsstrahlung radiation is produced as the electrons travel a short distance from the negative cathode to the positive anode in the x-ray tube.

Increasing mA increases the number of electrons which thereby increases the number of x-rays. Increasing the kVp increases the penetration of the beam which thereby increases the number of x-rays that will reach the film. Increasing the filter thickness or atomic number increases the hardness of the beam, but reduces quantity. Increasing the atomic number increases the number of electrons available for interaction which thereby increases the number of x-rays.

It is important for radiographers to use the right chart for the right room for the right purpose.

Medical radiographers are able to adapt to a wide variety of x-ray generating equipment because of common controls on the operator's console.

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[1] Bushong, SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis, MO: Mosby, Inc., 2001.
[2] Selman, J. *The Fundamentals of X-ray and Radium Physics.* 4th ed. Springfield, IL: Charles C. Thomas, 1970.

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UNIT NUMBER ___3___

FACTORS AFFECTING THE RADIOGRAPHIC IMAGE — DENSITY

PREPARED BY: Carolyn J. Frigmanski, M.A. B.S.R.T. (R)

INTRODUCTION

In this unit we will define density and the major factors that influence the resultant optical densities on our finished radiographs. Density is only one major influence on overall quality. Contrast, detail, distortion and blur also influence optical density and image quality. These factors will be discussed in other units.

RADIOGRAPHIC QUALITY

One of the primary responsibilities for diagnostic radiography personnel is to produce consistent, good quality radiographic images. A quality radiograph is determined by evaluating two essential criteria. The first category is relative to <u>sharpness</u> of detail and involves geometric factors that we utilize in creating the image such as focal spot selection, source image distance, object film distance, etc. The second category of radiographic quality is the <u>visibility</u> of detail and involves exposure factors that we select on our control panels such as kilovoltage, mA, time, etc. The creation of the <u>sharpness</u> and <u>visibility</u> of information that is available on the film for final interpretation is at the discretion of the radiographer making the exposure. Some of the decision-making is restricted based on the type of the equipment utilized, manual versus automatic exposure, structured technique charts and department protocols. However, as we all know, there is an art portion to our job performance that takes into account the adaptability of radiographers to meet the needs of patients in less than ideal situations. When we define or discuss radiographic quality, we would like to have anatomic structures displayed as accurately as possible by providing the appropriate levels of detail, contrast and density to enhance the differences in tissue densities and overall esthetic quality of the finished radiograph.

DENSITY

By definition, density is considered the overall blackness on the finished radiograph. Density is controlled by the milliamperage selected on the control panel.[1(p155)] mA controls the number of electrons available to produce the required number of x-rays in the x-ray tube. Time determines the length of exposure the patient receives the radiation. Obviously, higher mA and longer time selections will provide a greater degree of blackening or density on a finished radiograph in comparison to a radiograph of an equivalent body part with lower mA and shorter time. Therefore, one of our fundamental concepts in using milliamperage and time is to calculate mAs.

THE mAs FORMULA

mA x seconds = mAs[2(p156)]

It is easy for us to manipulate mA or time to produce images of equivalent density or blackness when one of the variables needs to be changed. The reciprocity law allows us to manipulate mA or time to come up with the same resultant density when the mAs is equivalent. For example, if I select 100 mA at 1/5 second, I will have 20 mAs. If I choose to use 200 mA at 1/10 second, I will also have 20 mAs so that both of the resultant images will have the same degree of blackening. If motion is a consideration for these two exposure choices, it is wiser to select the 200 mA at 1/10 second. The shorter time would minimize the risk of any motion that would be detrimental to image quality.

Many of us in our clinical practice do these calculations automatically and have internalized the mathematics by our repetition of performing radiographs in the department. Some radiographers who may have been utilizing automatic equipment for a prolonged period of time may have forgotten some of these fundamentals. This repetitious exercise serves as a reminder to all of us. The answers have been provided for your convenience.

LET'S CALCULATE mAs

You have selected 300 mA at .4 seconds. What is the mAs?

300 x .4 = 120 mAs

Calculate the mAs for these combinations:

300 mAs at 1/2 second	Answer = 150 mAs
200 mAs at .6 seconds	Answer = 120 mAs
100 mAs at 3/20 seconds	Answer = 15 mAs

How about these?

100 mAs at .2 seconds — Answer = 20 mAs

200 mAs at .4 seconds — Answer = 80 mAs

50 mAs at .6 seconds — Answer = 30 mAs

By manipulating either mA or time, we can solve an unknown factor and arrive at the appropriate exposure to give the required optical density on our film. In the first two problems we are going to be solving for a mA selection that will produce 60 mAs. To solve these problems, we simply divided the time into the mAs. As we know, repetition is the best form of learning so we will do the exercise again in the next problem. The answers are provided for you.

What mA will give us the desired mAs?

________ mA x .3 second = 60 mAs — Answer = 200 mA

________ mA x .1 second = 60 mAs — Answer = 600 mA

________ mA x .1 second = 40 mAs — Answer = 400 mA

In the next set of problems, we have the mA provided and must solve for the correct time to give us the resultant mAs. In solving these problems, it will be necessary for us to divide the mA into the mAs. The answers are provided for you.

What time will give us the desired mAs?

300 Ma x _______ second = 240 mAs — Answer = 8/10 or .8 seconds

200 Ma x _______ second = 150 mAs — Answer = 3/4 or .75 seconds

INVERSE SQUARE LAW

As radiography students in our previous lives, we have had appropriate instruction in the principles of the Inverse Square Law. As a refresher, we will simply review the principle and the formula. We will then apply it in the clinical situations described in the next two paragraphs.

The Inverse Square Law states that the intensity of the x-ray beam is inversely proportional to the square of the distance from the source.[2(p65)] To demonstrate this in a mathematical relationship, we use the formula listed below.

$$\frac{\text{Old/original mAs}}{\text{New/unknown mAs}} = \frac{\text{New Distance}^2}{\text{Old Distance}^2}$$

I have substituted the factor mAs with what you may have previously learned as the factor named Intensity. Since most of us use mAs in our diagnostic applications, I felt it would be easier to identify with this factor rather than using intensity. Sometimes it is written out with a big "E" for exposure.

We are now ready to proceed with the Inverse Square Law example. A portable chest is ordered in the E.R. You have enough distance to film at 2 distances: you can choose 40" S.I.D./F.F.D. or you could choose 60" S.I.D./F.I.D.

Which do you want to choose to minimize **your** exposure?

Which do you want to choose to minimize the **patient's** exposure?

In determining the answer for the first question, you want to select the 60" S.I.D. or F.F.D. because we know that the farther we are away from the beam, the less intense the radiation will be for radiographers. In the second question relative to the patient's exposure, we know that the closer the beam is to the patient, the more intense it will be and we can reduce the amount of primary radiation reaching the patient.

In practice, the farther you are away from the x-ray beam, the less the exposure dose to **you**!

Now, let's move on to a situation in clinical practice demonstrating the effects of the Inverse Square Law.

PORTABLE CHEST PROBLEM

A technique of 5 mAs was used at 90 kVp with a 40" S.I.D. kVp is not influenced by varying distances. If we use our formula, we can calculate what the resultant mAs would be when we change our original 40" S.I.D. to 60" S.I.D. without compensating in the exposure factors.

You will need to calculate the intensity of the beam at 60". The formula set up has been provided to you. You simply need to either reduce the distance numbers to square smaller numbers or you may square the larger distance numbers if you choose. Once you have changed the numbers, you simply cross-multiply and make a single division to come up with the resultant answer.

Formula: $$\frac{\text{Old/Original mAs}}{\text{New/Unknown mAs}} = \frac{\text{New Distance}^2}{\text{Old distance}^2}$$

Step 1 $$\frac{5 \text{ mAs}}{X \text{ mAs}} = \frac{60''^2 \text{ S.I.D.}}{40''^2 \text{ S.I.D.}}$$

Step 2 $$\frac{5 \text{ mAs}}{X \text{ mAs}} = \frac{60^2}{40^2}$$ reduce down

Step 3 $\frac{5 \text{ mAs}}{X \text{ mAs}} = \frac{3^2}{2^2}$

Step 4 $\frac{5 \text{ mAs}}{X \text{ mAs}} = \frac{9}{4}$

Step 5 Cross multiply $9X = 20$ mAs
$X = 2.22$ mAs

$X = 2.22$ mAs *The resultant image will be underexposed unless you compensate for the added 20".

If you have performed the calculations as listed above, you will see that the resultant mAs would be equivalent to 2.22 mAs. The image will be under-exposed at 60" if you do not compensate by adding additional mAs based on the reduced intensity of the primary beam.

Let's calculate another situation.

A technique of 300 mA at .3 seconds was used at 40" S.I.D. What is the intensity of the beam at 60"?

Formula set up	Reduce the distance number	cross-multiply	
$\frac{90 \text{ mAs}}{X \text{ mAs}} = \frac{60^2}{40^2}$	$\frac{90 \text{ mAs}}{X \text{ mAs}} = \frac{3^2}{2^2}$	$9X = 360$ mAs $X = 40$ mAs	Answer = 40 mAs

COMPENSATION FORMULA

Most physicians do not want us to demonstrate the phenomenon of the Inverse Square Law in our clinical practice. They want us to be able to arrive at appropriate exposure corrections when distances have been altered so that image quality can be maintained. We then need to apply the Compensation Formula. It is a directly proportional relationship between mAs and distance. Please see the formula listed below.

Formula: $\frac{\text{Old/Original mAs}}{\text{X/Unknown mAs}} = \frac{\text{Old Distance}^2}{\text{New Distance}^2}$

Let's use the same example in the portable chest problem demonstrating the Inverse Square Law. When the distance is altered from 40" to 60", it is necessary to increase the mAs to an 11.25 to produce an equally diagnostic image.

Formula: $\frac{\text{Old/Original mAs}}{\text{X/Unknown mAs}} = \frac{\text{Old Distance}^2}{\text{New Distance}^2}$

$\frac{5\ mAs}{X\ mAs} = \frac{40''^2}{60''^2}$ $\qquad \frac{5\ mAs}{X\ mAs} = \frac{2^2}{3^2}$ $\qquad \frac{5\ mAs}{X\ mAs} = \frac{4}{9}$ $\qquad$ Answer: $4x = 45$ mAs

Reduce the distance number $\qquad$ cross-multiply

X = 11.25 mAs must be used to produce an equally diagnostic image with the added 20" S.I.D.! Please review the next problem in which an AP skull was performed with 10 mAs at 40" and the distance was increased to 100". Please calculate the new mAs for the new S.I.D.

AP skull: $\frac{10\ mAs}{X\ mAs} = \frac{40''^2}{100''^2}$ $\qquad \frac{10\ mAs}{X\ mAs} = \frac{2^2}{5^2}$ $\qquad \frac{10\ mAs}{X\ mAs} = \frac{4}{25}$ $\qquad$ Answer: $4x = 250$ mAs, $X = 62.5$ mAs

The lateral was obtained at 5 mAs at 40" with the same increase in distance. Please calculate the appropriate compensatory mAs to produce AP and lateral skull films of equivalent density.

Lateral skull: $\frac{5\ mAs}{X\ mAs} = \frac{40''^2}{100''2}$ $\qquad \frac{5mAs}{X\ mAs} = \frac{2^2}{5^2}$ $\qquad \frac{5\ mAs}{X\ mAs} = \frac{4}{25}$ $\qquad$ Answer: $4x = 125$ mAs, $X = 32.25$ mAs

Our last compensation problem is provided to you with the answer.

100 mAs was used at 36" S.I.D. The distance was changed to 72" S.I.D. What new mAs should be used to obtain the same film density?

$\frac{100\ mAs}{X\ mAs} = \frac{36''^3}{72''^2}$ $\qquad \frac{100\ mAs}{X\ mAs} = \frac{1^2}{2^2}$ $\qquad 1x = 400$ mAs $\qquad$ Answer: 400 mAs

Reduce distance numbers $\qquad$ cross multiply

ANODE HEEL EFFECT

We know there is a variation in the intensity of the primary beam as it exits the x-ray tube due to the beveled edge of the anode. The beam is less intense on the anode end of the tube and more intense at the cathode end of the tube.[1(p132)] The central ray (the most perpendicular portion of the beam) has an intensity of 100%.[1(p133)] Since more of the x-ray beam will be deflected to the cathode portion of the tube, the intensity will range between 105 or 110%. By the same token, if we measure the intensity of the beam at the anode end, we will find that the intensity ranges between 75-95%. It is important for us to remember to keep the thinner portion of the patient's body part to the anode of the tube and the thicker portion of the patient's body part to the cathode end of the tube. In this manner we can provide a more uniform density on our resultant images of body parts of varying thicknesses. All x-ray tubes have their anodes and cathodes identified either by a full name or +/- symbol. The anode is the positive terminal and the cathode is the negative terminal. You can accomplish this principle by simply turning the tube to the correct alignment of the patient's body part or reversing the patient's position on the table for certain examinations.

SENSITOMETRIC CURVES

Synonyms in the past for sensitometric curves have been characteristic curves and H & D which represent Hurter and Driffield, the two gentlemen who designed this method of measuring film sensitivity.[1(p256)] Sensitometric curves provide a measured display of optical densities on the film after it has been sensitized, processed, and then charted on some graph paper. We know that the numbers calculated on each of the density steps on our sensitometric strip are a comparison of incident light in the processed film to the light that is transmitted through it and converted to a logarithm number.

We have also identified parts of the sensitometric curve. We know the toe, which is a combination of the base plus fog density, is in the low range of 0.2 to 0.25.[1(p256)] Film bases usually have a dye added to them to make them less tiring to view with the human eye.

The average gradient, or the straight-line, portion of the curve provides us information about the scale of contrast that will be inherent in the film by the manufacturer.[1(p256)] It provides us information if we should choose to manipulate variables that the film may be subjected to. For example, we may want to consider doing a temperature series and then plotting all the sensitometric curves for each temperature degree to find out which temperature provides the desired density and contrast. The speed factor, or point, is the step that represents the whole number 1.0 + base and fog. It is our standard reference for density calculation.

The shoulder is the uppermost curve portion that brings us into the higher black ranges, like 2 to 2.5.[1(p256)] At the very top of the curve, we have our D-max or the density maximum, which is the blackest black that can be provided on the particular film selected. The D-max is somewhat non-diagnostic because the blackest-black does not give us information of any useful means.

We have discovered that in looking at overall radiographic quality, films possessing a density range of 0.25 at the toe up to 2.0 at the shoulder allow maximum radiographic quality with the appropriate levels of contrast and density. Please refer to the sensitometric chart at the conclusion of this unit.

BODY HABITUS CONSIDERATIONS

On any particular day we experience a wide variety of patient shapes and sizes in our clinical practice.[1(p269)] There are four major categories of patient architecture. Hypersthenic patients are extremely large, very broad in the shoulders and chest, and have visceral organs that are usually located in a higher and lateral position within the abdomen.[1(p277)] Classic examples would be Hulk Hogan or Refrigerator Perry.

Sthenic patients are patients we consider of average or normal size and shape.[1(p277)] Approximately 50% of the U.S. population are estimated to be in this category. I am not quite sure that this statistic truly reflects the current population of Americans. A new study is presently being conducted in the United States.

Hyposthenic patients are less than average in size and shape and could be considered by some folks as underweight.[1(p277)] They have long lungs and visceral organs that are usually located lower and in a medial position within the abdomen.

Asthenic patients are the extremely thin, emaciated people who we commonly categorize as the anorexics or picture as prisoners who were released from Nazi prison camps.[1(p277)] The organ location is similar to hyposthenics.

Resultant density on our films will be directly affected by the body size and thickness of the patient. Hypersthenic patients will obviously absorb more radiation with a resultant decrease in density on film. They necessitate an increase in our primary exposure factors to compensate for the absorption of the x-ray beam. By the same token, asthenic patients have less body tissue and less density within their structures. We will need to substantially reduce our primary factors of exposure so that we do not over-expose the patient or provide images that are too dark for interpretation.

COMPENSATORY FILTERS

We historically have used compensatory filters to a greater degree than what we use today. These are filters added to the beam that are specifically designed to accommodate varying body thicknesses and tissue densities.[1(p161)] When the filter is used appropriately, it can provide a more uniform density on the film. Several names for compensatory filters include wedge, trough and commercial models for specific use.

An example of a wedge filter is a triangular piece of metal that is inserted in the tube housing with the thick end of the filter at the thinnest end of the body and the thin end of the filter at the thicker portion.[1(p161)] If we are using a wedge filter on an AP dorsal spine projection, we would have the cervical portion of the patient's body at the thick portion of the filter and the lower dorsal/lumbar portion of the patient's body at the thinner portion of the filter. In this manner we can eliminate the added blackness at the cervical area and the loss of density at the dorsal/lumbar region. It produced a better-exposed AP dorsal spine.

A second type of compensatory filter, commonly used in chest radiography, is the trough filter. It has a thinner central portion and thicker peripheral portions.[1(p162)] The trough filter will allow greater penetration and density through the mediastinum. The thicker portions of the filter on the periphery will prevent the lung tissue from being burned out or too dense for appropriate visualization of the bronchovascular markings.

The third category of commercial filters can be used in such dedicated studies as scoliosis filming and some angiography interventional type procedures.

SUMMARY OF EXPOSURE AND TECHNICAL FACTORS AFFECTING DENSITY

We have completed some exercises in solving for variable mA and time selections. We have also utilized the Inverse Square Law and Compensation Formula in fictional situations. A summary on exposure and technical factors that affect the overall density on our finished radiographs and the total radiographic quality are described below.

1. mA - higher mA = greater density

A primary consideration when selecting factors on a control panel involves the mA. We know that milliamperage determines the number of x-rays produced and therefore the resultant density or blackness on the film.[1(p247)] mA is directly proportional to density. The higher the mA selected the greater density or blackness will be on the resultant image. It is important for us to provide the appropriate density level to demonstrate anatomic structures without under- or over-exposing the patient to radiation.

2. Time - longer time = greater density

Time obviously controls the length of radiation exposure that the patient receives for each particular radiograph. In addition, time is of significant importance to us because it helps us minimize the risk of patient motion.[1(p248)] Regardless of how well you set the technical factors on the operator console, patient motion will necessitate a repeat. It is very important to solicit patient cooperation whenever possible to minimize the risk of motion and to select the shortest time possible on the equipment that you are utilizing. Time and mA can be manipulated if change is necessitated because of patient motion.

3. kVp - higher kVp = greater density

Higher kVp provides us greater density on our finished radiograph because the x-ray beam is more penetrating, thereby, allowing more of the x-rays to go through the patient to reach the film.[1(p156)] The primary control of beam quality, the penetration of the beam and the scale of contrast is directly influenced by the kilovoltage selected on the control panel. Body parts that are not appropriately penetrated will not give us the information needed to delineate small hairline fractures and other structural abnormalities. The scale of contrast, if inappropriately utilized, may disguise valuable diagnostic information. An image possessing long scale contrast or lots of grays may disguise a small calculus.

When kilovoltage is selected by the radiographer, the recommended or optimum kVp should be determined by established protocols and published information. A listing of recommended or optimum kVp is provided below.[1(p289)]

small extremity, (toes, fingers, hand, foot, etc.)	50-60 kVp range
larger extremities (lower leg, femur, forearm, humerus, etc.)	70-80 kVp range
skull	80 kVp
abdomen	70-80 kVp range
chest	100+ kVp

4. Distance - shorter distances = greater density

Source image distance is focal film distance as its older synonym. It is a geometric fact that the longer the source image distance/focal film distance is, the greater will be the detail demonstrated on the finished radiograph.[1(pp249-250)] Because of the influence of the Inverse Square Law, the exposure to radiation by the patient will increase as distance is shortened and decreases as distance increases. We need to arrive at a reasonable distance that meets both the patient dose considerations as well as detail information.

5. Patient Tissue Densities

It is important to understand the two categories of disease processes that affect radiographic density.

The first category is considered additive diseases.[1(p278)] The tissue has increased densities or atomic number materials within our bodies. Examples of additive diseases would be hydrocephalus due to the increased amount of cerebral spinal fluid in the ventricles of the brain or cirrhosis due to the ascites found in the abdomen. When an additive disease process exists, we need to increase our exposure to compensate for the x-rays that will be absorbed by the abnormal tissue or fluid collections. An increase of 4 kVp will be required under 100 kVp; a 6-8 kVp increase will be required over 100 kVp.

The second category is destructive diseases.[1(p278)] The tissue is less dense or has lower atomic number materials than normal. For example, a patient with osteoporosis has less dense compact bone in their extremities than a person of normal bone composition. Therefore, destructive diseases warrant a decrease in exposure. A decrease of 4 kVp will be required under 100 kVp; a 6-8 kVp decrease will be required over 100 kVp.

A short listing is included for your review.[1(p278)]

DESTRUCTIVE DISEASES (EASY TO PENETRATE)	ADDITIVE DISEASES (HARD TO PENETRATE)
Atrophy	Edema
Bowel obstruction	Pleural effusion
Emphysema	Pneumonia
Degenerative Arthritis	Cirrhosis
Osteoporosis	Hydrocephalus
Active tuberculosis	Paget's disease
Carcinoma	Pneumoconiosis
Multiple myeloma	Osteoma

If the scale of contrast changes too dramatically with the kVp changes, mAs may be halved or doubled.

6. Screen Speed - faster screen speeds = greater density[1(p208)]

Another consideration is screen speed. We know that as we select faster screens we can provide greater density while minimizing our radiation dose to the patient.

7. Sensitometric Curve - faster film = greater density

One method we can use to evaluate film speed is to perform sensitometry testing. We expose a sheet of film with the sensitometer, process it, and then measure the steps of density on the resultant strip with the densitometer.[1(p256)] The density readings are calculated on the light transmitted through the film and the incident light as a logarithm reading. The numbers for each step are then plotted on graph paper and a curve can be drawn connecting the sensitometric dots on the graph paper. Obviously, faster film, when plotted, will have a greater response to radiation than films that are slower. In comparing film products, it is important for us to do sensitometric studies so that the promises made by the commercial vendors are in fact true. We can verify other variables that are inherent in the film that need consideration such as latitude, the average gradient or scale of contrast, etc. We will get into a further discussion on sensitometric curves in Unit 7.

8. Developing time and temperature - longer time and higher temperature = greater density

We must take into consideration that developing time and temperature will affect the resultant density on our films.[1(p262-264)] We realize that longer times in the developing solution at higher temperatures will increase the density or blackness on the film. It has been estimated that a three-degree temperature increase in automatic developing will constitute a 25% increase in overall blackness.

9. Fog

Fog is any unwanted, unnecessary density on the film that render no diagnostic value and deters our overall radiographic quality.[1(p258)] Common fog factors are chemical, light, age of film, etc. These factors will be discussed in Unit 7.

10. Beam Restriction

Any device used to restrict the primary beam will correspondingly reduce the amount of secondary radiation that is helpful in providing density to the overall image.[1(p221)] When we restrict the primary beam, we reduce the overall density on the image. We must compensate with our primary exposure factors initially to provide adequate density.

11. Grids

We know that grids are composed of lead strips and lead absorbs radiation.[1(p233)] We also know that the lead strips are arranged so that the amount of scatter radiation can be minimized before it reaches the film. Grids definitely affect radiographic density or the overall resultant blackness. We must compensate with correction factors to produce the desired density when a grid is incorporated in a diagnostic examination. By the same token, if we choose to do a standard grid study non-grid, we need to make correction by reducing our exposures.

12. Air Gap

Air gap requires us to increase the object distance to the film to create an alternative method to a grid.[1(p244)] The scatter radiation will not interact with the film surface to the same degree it would if the patient was adjacent to the film. Using an air gap requires an increased source image distance to compensate for the loss of detail by the purposeful object image distance. Patient exposure must be increased. Therefore, the air gap technique is not utilized in clinical practice to any great extent. Cervical, chest and some angiographic applications use this principle.

13. Compression

Compression devices help us to unify body tissues that may be somewhat irregular in size.[1(p585)] If we take the classic example of the "beer belly", we know that, if the patient can sustain lying prone, we will get a better quality radiograph by providing more consistent thickness in the overall volume of the patient's abdomen. Our radiographic quality will improve.

14. Contrast Media

Contrast media can be categorized as negative, which means the density is increased on the film. Most of our negative contrast media are gases.[1(p348)] Because they are radiolucent, the contrast medium appears as a blackness in comparison to surrounding tissue.

The second category is positive which means the density is white on our finished radiographs. Most of our positive contrast media are barium or iodine-based solutions or suspensions which provide opacity to structures. Of course we have designed examinations that require both positive and negative contrast media to enhance diagnostic information. We commonly refer to these as double contrast studies.

15. Filtration

The primary purpose of filtration is to harden the beam and improve the quality of radiation.[1(p157)] Most filters or half value layers are fixed in the tube housing so that they are not easily retrieved by radiographers. In the past we were able to change the thickness of the filter and the atomic number of the filter by selecting other elements such as tin and copper. This capability has been restricted by the minimum Half Value Layer requirements recommended for use in diagnostic equipment from the National Council on Radiation Protection. We know that filtration reduces the quantity of x-rays that exit the tube because the soft wavelengths will be absorbed by the thickness and atomic number of the filter. When we increase filtration, we reduce the quantity of x-rays. The density will be decreased unless we compensate with our primary exposure factors.

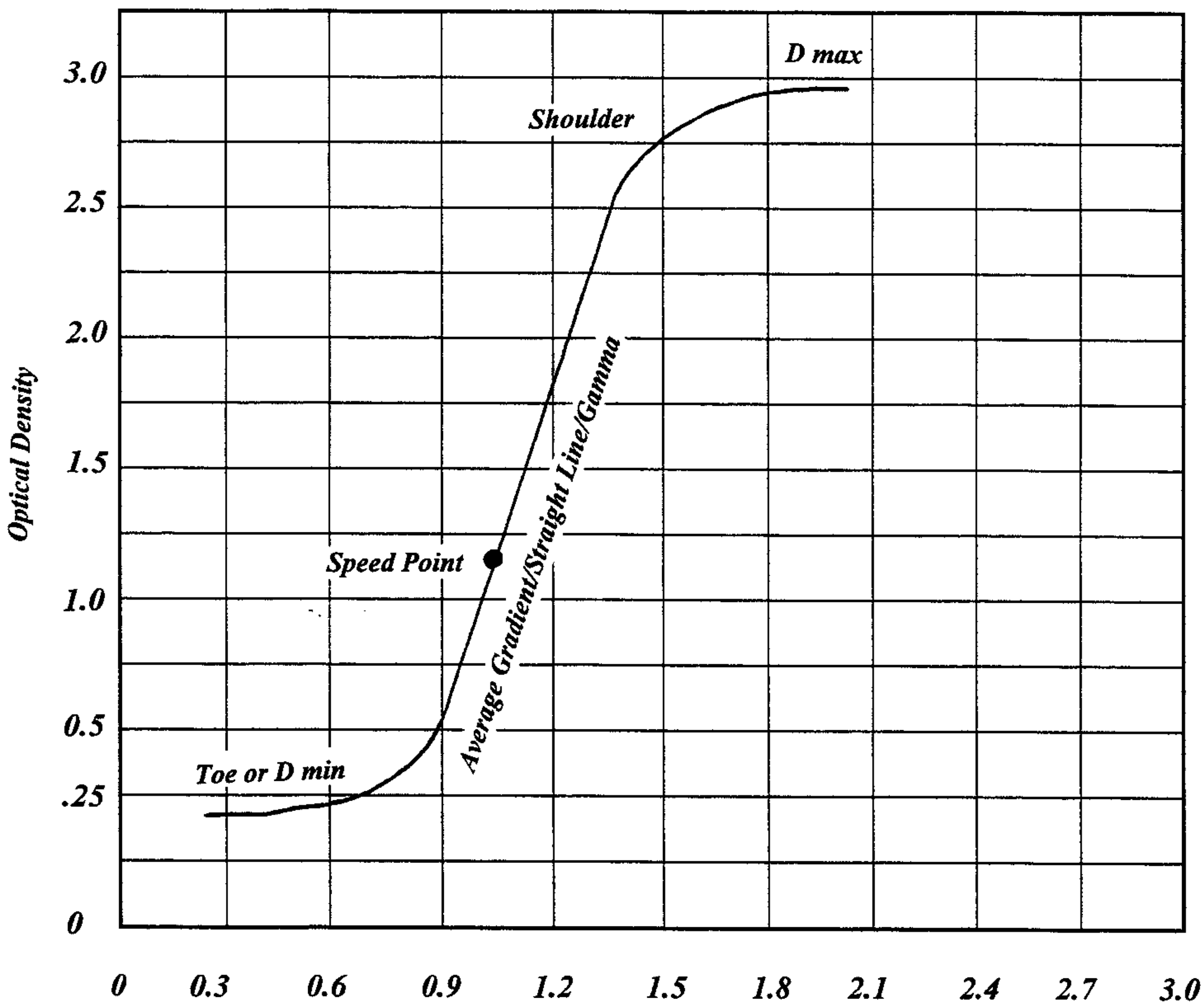
16. Type of x-ray generation

We know that single-phase equipment is not as efficient or possesses the higher capacities of radiation exposure that we find in three-phase generation equipment.[1(p116)] We need to take the type of generation into consideration. Three-phase equipment has less fluctuation in kilovoltage which therefore provides a more consistent primary beam and a more stable mA to generate the required number of x-rays in the primary beam to enter the patient. However, we realize that three-phase equipment may be cost prohibitive in some facilities or in some applications. Equipment options may be controlled by the Medical Physics staff or the existing equipment in the facility.

This concludes unit 3. Please proceed to the unit questions and complete the required personal data.

Sensitometric Curve (Characteristic or H & D Curve)

Useful Range of Diagnostic Information = 0 .25 - 2.0



Log Relative Exposure on this axis.

As the number increases, the density increases.

Toe or D min = Base + Fog or least amount of density above fog level.
Average Gradient/Straight Line/Gamma = the slope of the straight line portion of the curve beginning at 0.25 + base + fog & ending at 2.0 = base + fog.
Speed Point = density of 1.0 above base + fog.
Shoulder = end of average gradient/gamma/straight line portion of curve.
D max = maximum density/blackness.

Some Important Terms and/or Concepts in Unit 3

Radiographic Quality
- Sharpness of detail and involves geometric factors that we utilize in creating the image such as focal spot selection, source image distance, object film distance, etc.
- Visibility of detail and involves exposure factors that we select on our control panels such as kilovoltage, mA, time, etc.

Density
- The overall blackness on the finished radiograph.
- Controlled by the milliamperage and time selected on the control panel.

Time
- Determines the length of exposure the patient receives the radiation.

mAs formula
- mA x seconds - mAs

Inverse square law
- The intensity of the x-ray beam is inversely proportional to the square of the distance from the source.
- The farther you are away from the x-ray beam, the less the exposure dose to you.

Compensation formula
- Directly proportional relationship between mAs and distance.

Anode heel effect
- Variation in the intensity of the primary beam as it exits the x-ray tube created by the beveled edge of the anode.
- Beam is less intense on the anode end of the tube and more intense at the cathode end of the tube.

Sensitometric curve/H & D/Characteristic curve
- Method of measuring film sensitivity.
- Display of optical densities on the film after it has been sensitized, processed, and then charted on some graph paper.
- Toe - combination of base plus fog density
- Average gradient or the straight-line portion of the curve provides information about the scale of contrast that will be inherent in the film by the manufacturer.
- Speed factor or point - step that represents the whole number 1.0 + base and fog. (standard reference for density calculation).
- Shoulder - uppermost curve portion that brings us into the higher black ranges
- D-max or the density maximum - blackest black that can be provided in the particular film selected.

- Films possessing a density range of 0.25 at the toe to 2.0 at the shoulder allow maximum radiographic quality with the appropriate levels of contrast and density.

Body habitus considerations

- Hypersthenic patients - extremely large, very broad shoulders and chest and have visceral organs that are usually located in a higher and lateral position within the abdomen.
- Sthenic patients - average or normal size and shape.
- Hyposthenic patients - less than average in size and shape and could be considered underweight, have long lungs and visceral organs that are usually located lower and in a medial position within the abdomen.
- Asthenic patients - extremely thin, emaciated who are commonly categorized as anorexics, organ location is similar to hyposthenics.

Compensatory filters

- Added to the beam and specifically designed to accommodate varying body thicknesses and tissue densities.

Exposure and technical factors affecting density

- mA - higher mA = greater density
- Time - longer time = greater density
- kVp - higher kVp = greater density
- Distance - shorter distances = greater density
- Screen speed - faster screen speeds = greater density
- Sensitometric curve - faster film = greater density
- Developing time and temperature - longer time and higher temperature = greater density
- Fog - unwanted, unnecessary density on the film that renders no diagnostic value and deters overall radiographic quality
- Air gap - requires us to increase object distance to the film to create an alternative method to a grid
- Compression devices - helps to unify body tissues that may be somewhat irregular in size
- Contrast media -
  Negative - density is increased on the film
  Positive - density is white on finished radiographs
- Filtration - primary purpose is to harden the beam and improve quality of radiation

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[1] Bushong, SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis: MO: Mosby, Inc., 2001.

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UNIT NUMBER 4

FACTORS AFFECTING THE RADIOGRAPHIC IMAGE - CONTRAST

PREPARED BY: Carolyn J. Frigmanski, M.A., B.S.R.T. (R)

INTRODUCTION

In this unit we will discuss contrast and the factors that influence the scales of contrast we provide on our diagnostic radiographic images. We will also be doing some simple mathematical calculations relative to kVp and mAs adjustments when the exposure factors have to be altered.

CONTRAST

The term contrast relates to the various optical densities we see displayed on a finished radiograph. It is sometimes described as the tonal values of density found throughout the radiographic image.[1(282)] Since there are multiple shades of blacks, grays and whites in the scale of contrast, we use two descriptive terms to refer to it. The first term is called long scale contrast with the synonym of low contrast.[1(283)] It reflects the multiple shades of blacks, grays and whites to a finished radiograph. The second term is called short scale contrast with a synonym of high contrast. The finished radiograph has a distinctive black and white quality with very few shades of gray. It is very esthetically pleasing to the eye and is helpful for certain examinations. However, some examinations require a longer scale of contrast to gain the most diagnostic information for the physician.

DESCRIPTIVE TERMS FOR CONTRAST

In our day to day activities we use terms that may be confusing relative to the contrast on our finished films. When an image possesses high contrast, it has certain characteristics. These characteristics are fewer shades of gray which correspond to a shorter scale of contrast. These images are also described as possessing increased contrast and are produced by using low kVp ranges.

The second term, low contrast, refers to images possessing many shades of gray and is described as long scale.[1(p283)] These images have decreased contrast and are produced by using higher kVp levels that render the image with less contrast.

We also know that the length of time the film is in the developing solution reflects the amount of optical density that may be manifested. When films are in the developer for less than the recommended time, long scale contrast will result.[1(p283)] In addition to processing conditions, the manufacturer provides inherent contrast of different scales when manufacturing screen versus nonscreen film. Screen film will possess higher contrast (short scale) than nonscreen film by comparison.

TWO TYPES OF CONTRAST

The overall resultant scale of contrast on the film is produced by two factors. The first type of contrast is inherent in the patient and is called subject contrast. It is determined by the size, shape, and the x-ray absorbing characteristics of the anatomic tissues within the patient.[1(p259)] The second type of contrast is inherent in the film and is called film contrast. It is provided by the manufacturer of the film product. Film contrast is influenced by processing conditions. The combination of subject and film contrast produces the scale of contrast on the finished radiograph. We will look at the factors that influence each of these types of contrast in the next several paragraphs.

FACTORS INFLUENCING SUBJECT CONTRAST

We know that the scale of contrast is influenced by the absorption of radiation by anatomic tissues. Therefore, patients possessing greater thicknesses of anatomic tissue will have images possessing a long scale (less contrast).[1(p282)] The patients who have greater tissue densities will absorb more of the radiation entering their body and therefore produce images possessing a long scale (less contrast). Depending on the atomic number of the tissues, the scale of contrast can be affected. Tissues that have higher atomic numbers will produce long scale (less contrast).

The shape of the patient's anatomical part may influence the scale of contrast. Body parts that have irregular shapes will produce images having long scale (less contrast).[1(p283)] A classic example of this would be a patient lying supine on the table who has a distended abdomen in the characteristic shape of a "beer belly". The highest portion of the abdominal tissue will absorb more radiation preferentially than the less-thick portions of the abdomen.

The last factor that affects subject contrast is kVp.[1(p283)] kVp is the single most important factor that affects the scale of contrast. When high kVp is used, long scale contrast is generated. When low kVp is used, short scale contrast is generated. Therefore, it is important to consider the level of kVp and the body part being examined to produce resultant images possessing satisfactory contrast characteristics.

FACTORS AFFECTING FILM CONTRAST

When a particular brand of film is selected in the department, it is important to do a sensitometric study on the film. Information can be obtained relative to the scale of contrast the film may produce under certain conditions. In evaluating the sensitometric curve, the slope of the straight-line portion represents the average gradient.[1(p256)] The average gradient demonstrates the significant optical densities that will be displayed on a step by step basis. Each step will be measured on a densitometer. The optical densities can be manipulated somewhat by processing conditions.[1(p257)] For example, if inappropriate or incorrect processing solutions are utilized, the scale of contrast will become long (low) because the image will possess chemical fog. When film is developed, an even and consistent submerging of the film in the chemistry must be maintained so that development occurs in an optimum manner. Films that are not agitated during processing will result in long scale (less contrast). We also know that film responds differently to different temperatures. When solutions are too hot, additional fogging will occur which renders the image long scale (less) contrast. We also know that the length of time the film is in the developing solution reflects the amount of optical density that may be manifested. When films are in the developer for less than the recommended time, long scale contrast will result.

In addition to processing conditions, the manufacturer provides inherent contrast of different scales when manufacturing screen versus nonscreen film. Screen film will possess higher contrast (short scale) than nonscreen film by comparison.

MAJOR FACTORS AFFECTING QUALITY

When we discuss the quality of the x-ray beam, we are referring to the penetration ability. The major factors that influence the quality of the beam are kVp and filtration. We will discuss each of these factors in the following sections.

KILOVOLTAGE SELECTION

The scale of contrast must be considered when selecting kilovoltage. Therefore, considerations for film and subject must be calculated in the final determination of the appropriate technique for different diagnostic examinations. Whenever possible, the recommended optimum kilovoltage for certain anatomic structures should be used as listed below.[1(p289)]

Small extremities	50-60 kVp
Skull	80 kVp
Abdomen	70-80 kVp
Barium studies	in excess of 100 kVp
Chest	in excess of 100 kVp

Since the kilovoltage level has been determined, the mAs will need to be adjusted for the various body areas and thicknesses to provide the desired density. When a radiographer has to deviate from the selected optimum kV, the scale of contrast will be directly affected. As we have already mentioned, higher kilovoltage ranges will provide longer scales of contrast and lower kilovoltage ranges will provide short scale.

Once the mAs has been determined for the normal/average size patient with a phantom, adjustments can be made with mAs for varying patient sizes.[1(p288)] A 30-50% reduction in mAs while using optimum kVp is recommended for below average size patients. A 50-100% increase in mAs while using optimum kVp is recommended for above average size patients. Fine-tuning of mAs can be established with centimeter measurements when developing a technique chart.

THE 15% kVp RULE

When altering the optimum kVp range, radiographers have used a very simplistic method of 10 kVp. It was understood that if you added 10 kVp to an exposure, you could double the density; if you reduced 10 kVp, you could cut the density in half. This particular rule works effectively in the 70 kVp range. Because we do multiple examinations at different kilovoltage levels, it is important for us to understand a more comprehensive and accurate method of manipulating exposure factors to produce diagnostic images. The 15% rule can be applied to all kVp adjustments.[1(p284)]

To maintain radiographic density when increasing kVp by 15%, the mAs must be reduced 50%.[1(p284)] Let us use this example. An original technique of 20 mAs was used at 80 kVp. 15% of 80 kVp equals12. The correction for this radiographic exposure should be10 mAs at 92 kVp.

To maintain radiographic density when decreasing kVp by 15%, it is necessary to double the mAs. Let us utilize this example. The original film was exposed to100 mAs at 70 kVp. 15% of 70 kVp equals 10.5 kVp. Since obviously we cannot use a 0.5 on our operator console, we simply round it up to 11 or leave it a 10 kVp. Therefore, the correction in the exposure factor should be 50 mAs at 80 kVp. Both of these images will be diagnostic; however, the images at higher kVp will provide longer scales of contrast.

LET'S CALCULATE kVp CHANGES

I am enclosing some preliminary problems for you to calculate with the provided answer. Please be sure you understand this major concept in controlling contrast.

Using the 15% kVp rule, calculate the new kVp if mAs is doubled:

		Answer
a.	64 kVp	Approximately 54 kVp
b.	90 kVp	Approximately 76/77 kVp

Using the 15% kVp rule, calculate the new kVp if mAs is halved:

a.	76 kVp	Approximately 87 kVp
b.	110 kVp	Approximately 126/127 kVp

SCATTERED RADIATION

After the primary radiation enters the patient, some may interact with the atoms of the patient's tissues. Some of the primary radiation will be absorbed by the patient. Some of the primary radiation will create secondary radiation that has been altered in its path due to collisions with the atomic nature of the patient. Some of the radiation will exit the patient and reach the film to produce the final image. Because scatter radiation is uncontrolled by the operator once it enters the patient, it is considered the radiographer's greatest threat to radiation exposure particularly during fluoroscopic examinations. The scattered radiation emanates from the patient in various directions with varying intensities. Scatter radiation is the primary reason why radiographers should not hold patients or subject others to assisting in immobilizing patients without appropriate protective apparel. Scatter radiation provides a fogging affect to the overall quality of the finished radiograph unless it can be manipulated appropriately.[1(p221)]

FACTORS AFFECTING CONTRAST

To control the amount of scatter radiation that we generate by the primary beam, it is important for us to control the x-ray beam field size. If the field size is larger than necessary, we produce a greater volume of scatter radiation to fog the film.

When thicker body parts are radiographed, we know that a greater amount of primary radiation is required.[1(pp224-225)] As we increase the primary radiation, we will also increase the amount of scatter generated in the patient that may exit and affect the overall quality of our finished radiograph.

We also know that denser body parts require greater amounts of primary radiation that produce a greater degree of scatter. Scatter affects the scale of contrast on our resultant image.

We know that increasing kilovoltage increases the amount of scatter. Therefore, it is always important to utilize the optimum kVp for a body part whenever possible.[1(p221)]

METHODS TO CONTROL SCATTER

Obviously it is important for us to control scatter radiation so that we can produce images of greater diagnostic value while minimizing some of the non-productive radiation that the patient will absorb. One of the primary ways we can control scatter is to control the size of the x-ray beam field. We have three major beam-restricting devices.

The first device is called an aperture or diaphragm.[1(pp225-227)] It operates in a manner similar to the lens of a camera or the pupil of the eye. It is composed of inter-leaving lead plates that can expand and contract in a circular size to allow more or less primary radiation to exit from the x-ray tube housing.

The second device is a cone that is attached to the x-ray tube. Cones come in various diameters and lengths. Cones can reduce the primary radiation field size based on the measurements of the selected cone.[1(p227)]

The third type of beam-restricting device is the collimator that comes in two varieties.[1(p228-229)] Manual collimator allows us to manipulate the dimensions of the beam size by hand. An automatic collimator will restrict the beam size when a cassette is placed in the bucky tray and the microswitches are activated.

Let's discuss manual collimators first. Manual collimators have two sets of shutters, an upper and a lower that are located in the collimator housing.[1(p228)] These work in a partnership arrangement to reduce the beam size in both directions. It is necessary for us to keep the field size the same or less than the size of the anatomic part under examination when diagnostic information is not jeopardized. It is never appropriate to open the beam size larger than the anatomic part under examination and the film size selected.

Automatic collimators operate on micro-switches that are located in the back portion of the bucky tray that holds the cassette.[1(p230)] When the film is locked in position in the bucky tray and inserted into the table, micro-switches will be triggered to restrict the pair of lead leaves in the collimator to correspond to the size of film located in the bucky. This positive beam limiting type or automatic collimator reduces the possibilities of radiographers exposing more tissue than absolutely necessary. However, in some examinations, it may necessary to collimate smaller than the film size. It is important for positive beam limiting type collimators to have a manual override so that radiographers can reduce the field size when necessary.

Years ago, it was necessary for radiographers to calculate projected field size to correspond to anatomic area and film size. Let's review these short formulas and practice a problem in each.

TO CALCULATE APERTURES[1(p227)]:

$$\frac{\text{focus-to-aperture distance}}{\text{S.I.D./F.F.D.}} = \frac{\text{aperture diameter}}{\text{film diameter or projected diameter}}$$

Here are the problems:

1. What is the size of the projected area for an aperture that is 1" in diameter with a 4" focus-to-aperture distance at a 40" focal film distance/S.I.D.?

$$\frac{\text{4" focus-to-aperture distance}}{\text{40" S.I.D./F.F.D.}} = \frac{\text{1" aperture diameter}}{\text{X film size or projected diameter}}$$

$$X = 10"$$

2. What is the size of the projected area for an aperture that is 2.5" diameter with a 6" focus-to-aperture distance at 36" focal film distance/S.I.D.?

$$\frac{\text{6" focus-to-aperture distance}}{\text{36" S.I.D./F.F.D.}} = \frac{\text{2.5" aperture diameter}}{X}$$

X = 15" film size or projected diameter

TO CALCULATE CONE COVERAGE: [1(p227)]

$$\frac{\text{film coverage diameter}}{\text{cylinder diameter}} = \frac{\text{F.F.D./S.I.D.}}{\text{focus to lower aperture distance and cone length}}$$

Here are the problems:

1. What is the size of the projected area for a cylinder cone that is 10 inches in length, 6" in diameter, at 40" S.I.D., if the focus-to-attachment distance of the cone is 3"?

$$\frac{\text{X film coverage area/projected area}}{\text{6"}} = \frac{\text{40" S.I.D./F.F.D.}}{\text{13" focus-to-lower aperture distance and cone length}}$$

X = 18"

2. What is the size of the projected area for a cylinder cone that is 12" in length, 8" in diameter, at 36" S.I.D., if the focus-to-attachment distance of cone is 4"?

$$\frac{\text{X film coverage area/projected area}}{\text{8"}} = \frac{\text{36" S.I.D./F.F.D.}}{\text{16" focus-to-lower aperture distance and cone length}}$$

X = 18"

USE OF EXTENSION CYLINDERS

When a cylinder cone was attached to the x-ray tube, the exposure factors had to be increased to compensate for the loss of scatter radiation that contributed to film density due to the small field size. Some cones could also be lengthened in a telescoping manner.

Primary exposure factors were adjusted as follows:

Half extended = Increase 40-60% mAs
Fully extended = Increase 100% mAs

TO CALCULATE COLLIMATOR COVERAGE:

It is necessary to do the calculations twice; one calculation is for width and the other is for length.

$$\text{Size of collimator in width} = \frac{\text{size of film width x focus-to-aperture distance}}{\text{F.F.D./S.I.D.}}$$

$$\text{Size of collimator in length} = \frac{\text{size of film length x focus-to-aperture distance}}{\text{F.F.D./S.I.D.}}$$

Here are the problems:

1. What is the dimension of the collimator if the projected size of field is 10" by 12" at 40" focal-film distance/S.I.D. with a 4" focus-to-aperture distance?

$$X = \frac{\text{10" x 4" focus-to-aperture distance}}{\text{40" S.I.D./F.F.D}}$$

X = 1" width of collimator area

$$X = \frac{\text{12" x 4" focus-to-aperture distance}}{\text{40" S.I.D./F.F.D}}$$

X = 1.2" length of collimator area

In other words, a 1" x 1.2" opening at the collimator would project a 10" x 12" field size at 40" S.I.D./F.F.D.

2. What is the dimension of the collimator if the projected size of field is 14" by 17" at 72" focal-film distance/S.I.D. with a 3" focus-to-aperture distance?

$$X = \frac{\text{14" x 3" focus-to-aperture distance}}{\text{72" S.I.D./F.F.D}}$$

X = 0.58" width of collimator area

$$X = \frac{\text{17" x 3" focus-to-aperture distance}}{\text{72" S.I.D./F.F.D}}$$

X = 0.71" length of collimator area

In other words, a 0.58" x 0.71" opening at the collimator would project a 14" x 17" field size at 72" S.I.D./F.F.D.

LATITUDE

Latitude is another characteristic of film response that is provided by the manufacturer. It allows radiographers to produce x-ray images with varying optical densities in a diagnostic range when exposure factors are altered.[1(p185)] Film manufacturers advertise their products as possessing wide or narrow latitude. Wide latitude film means the resultant images will have long scale of contrast. Narrow latitude film means the resultant images will be short scale. When wide latitude film is selected, radiographers may make errors in exposure calculations and still produce a diagnostic image. It may not be optimum, but acceptable. Narrow latitude film is very critical in exposure calculations. If a radiographer makes an error of a couple or several kVp, the resultant image may not be acceptable and necessitate a repeat. If many technologists are employed in a department, it is advantageous to select a film possessing wide latitude when multiple examinations are being performed. In this manner, fewer repeats may be necessary based on individual performance by multiple people. By the same token, if the radiographer is employed in a position which limits the number of people and types of examinations performed, a narrow latitude film may be to advantage because the level of expertise by the radiographer will be optimized and repeats should be minimized. Therefore, film possessing either wide or narrow latitude has appropriate places in the work environment. The selection of film latitude should be left to the discretion of the management personnel and physicians evaluating film quality.

FILTRATION

Filtration is considered the second most important factor that influences the overall scale of contrast produce on finished radiographs. Filtration is the process of shaping the beam to increase the ratio of photons useful for imaging to those photons that increase patient dose or decrease image contrast.[1(p159)] Filters remove low energy x-rays from the useful beam and increases its mean energy.

There are several types of filters that are installed in our tube housings. As radiation exits the tube, it must pass through the glass envelope and the window area. This is considered inherent filtration and usually has an equivalent level of 0.5 mm. of aluminum equivalent.[1(p160)] In addition to the inherent filtration, the medical physicists will recommend another layer of aluminum. This additional layer of aluminum is called added filtration. In the diagnostic radiography range, a 2.0 mm aluminum filter is recommended. Total filtration is the amount of inherent filtration and added filtration combined. In the diagnostic range, this corresponds to approximately 2.5 mm of aluminum equivalent.

These filtration amounts have been changed in recent years by the National Council of Radiation Protection. Their recommendations are now specified as Half Value Layers. Since it is not possible to measure the amount of inherent filtration in the x-ray beam, it is necessary to measure the half-value layer (HVL) of the beam.[1(p160)] The HVL is the amount of aluminum required to reduce the exposure to one-half of its original value (at a fixed kVp and mAs) and is not a measure of the amount of aluminum in the x-ray beam.

Recommended Filter Thickness vs. kVp[1(p159)]
Below 50 kVp = 0.3-0.5 mm Al
50-70 kVp = 1.2-1.5 mm Al
70 kVp and higher = 2.1-4.1 mm AL (FDA 1996)

In addition to these standard filtration requirements, some examinations may require the use of compensatory filters to provide a more consistent exposure when varying body thicknesses are evident. A classic example is a wedge filter. This triangular piece of metal has a thick and thin end.[1(p161)] We would often use the wedge filter in producing better quality foot radiographs. To utilize the wedge filter appropriately, the toe portion of the foot had to be located under the filter area that was thick in nature and the ankle portion of the foot was placed in relationship to the thin end of the filter. In this manner, when the primary beam entered the compensatory filter, the thick end of the filter absorbed more and the toes were not burned out by excess density. When the primary beam left the tube and entered the thin end of the filter, more primary radiation reached the thicker portion of the foot at the ankle. This relationship allowed us to provide foot films of more consistent exposure and diagnostic value.

EFFECTS OF FILTERS ON PATIENT EXPOSURE

When using a filter, radiographers must increase mAs.[1(p160)] The patient dose decreases due to the removal of "soft" x-rays. The x-ray tube puts out more photons, but the filter absorbs them, so the total number of x-rays reaching the patient actually decreases. The thicker the filter and higher the atomic number, the greater will be the reduction in the exposure rate beyond the film.

The purpose of filtration is to reduce the entrance skin dose to the patient by filtering out low kV x-rays. Filtration does not improve image quality.

EXPOSURE FACTORS AFFECTING CONTRAST

It is important for radiographers to understand the variables that will affect the overall image quality we produce. Therefore, we will summarize them in the following manner.

A. As kilovoltage increases, the scale of contrast decreases and is considered long.

B. As mAs increases, the scale of contrast decreases and is considered long.

C. As developing time increases, the scale of contrast decreases and is considered long.

D. As the x-ray beam field is reduced in size, the contrast increases or is considered short.

E. We have not discussed the application and impact of using various grid ratios and image receptors. We know that as grid ratio increases, the scale of contrast increases by reducing the amount of scatter radiation produced by the patient. We know that as film and screen speed changes, the resultant scale of contrast will also change. We will discuss these accessories in greater detail in Units 6 and 7.

This concludes Unit 4. Please proceed to the unit questions and complete the required personal data.

SOME IMPORTANT TERMS AND/OR CONCEPTS IN UNIT 4

CONTRAST

- relates to the various optical densities we see displayed on a finished radiograph.
- sometimes described as the tonal values of density found throughout the radiographic image.

LONG SCALE CONTRAST

- Patients possessing greater thickness will have images possessing long scale.
- Patients who have greater tissue densities will absorb more of the radiation entering their body and therefore produce images possessing a long scale (less contrast).
- Depending on the atomic number of the tissues, the scale of contrast can be affected.
- Tissues that have higher atomic numbers will produce long scale (less contrast).

SHORT SCALE CONTRAST

- finished radiograph has a distinctive black and white quality with very few shades of gray.

SHORTER SCALE OF CONTRAST

- images described as possessing increased contrast and produced by using low kVp ranges.

LOW CONTRAST

- long scale
- decreased contrast
- produced by using higher kVp rendering image with less contrast.

SUBJECT CONTRAST

- determined by size, shape and x-ray absorbing characteristics of anatomic tissues within patients.

FILM CONTRAST

- provided by manufacturer of film product.
- may be altered with processing conditions.

KILOVOLTAGE

- Whenever possible, the recommended optimum kilovoltage for certain anatomic structures should be used.
- To maintain radiographic density when increasing kVp by 15%, the mAs must be reduced 50%.
- To maintain radiographic density when decreasing kVp by 15%, it is necessary to double mAs.

SCATTERED RADIATION

- Uncontrolled by operator once it enters the patient.
- Radiographer's greatest threat to radiation exposure particularly during fluoroscopic examinations.
- Primary reason why radiographers should not hold patients or subjects others by assisting in immobilizing patients without appropriate protective apparel.

FACTORS AFFECTING CONTRAST

- If field size is larger than necessary, a greater volume of scatter radiation to fog the film is produced.
- When thicker body parts are radiographed, the amount of scatter generated in the patient increases.
- Denser body parts require greater amounts of primary radiation that produce a greater degree of scatter.
- Increasing kilovoltage increases the amount of scatter.
- Positive beam limiting type or automatic collimator reduces possibilities of radiographers exposing more tissue than absolutely necessary.

LATITUDE

- Allows radiographers to produce x-ray images with varying optical densities in a diagnostic range when exposure factors are altered.

WIDE LATITUDE

- Radiographers may make errors in exposure calculation and still produce a diagnostic image.

NARROW LATITUDE

- Very critical in exposure calculations.

FILTRATION

- Process of shaping the beam to increase the ratio of photons useful for imaging to those photons that increase patient dose or decrease image distance.
- By removing low energy x-rays from the useful beam, its mean energy increases.

HVL

- The amount of aluminum required to reduce the exposure of one-half of its original value (at a fixed kVp and mAs)
- It's no longer a measure of the amount of aluminum in the x-ray beam.

EFFECTS OF FILTERS ON PATIENT EXPOSURE

- When using a film, radiographers must increase mAs.
- Purpose of filtration is to reduce the entrance skin dose to the patient by filtering out low kV x-rays.

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[1] Bushong, SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis, MO: Mosby, Inc., 2001.

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P.O. Box 2931 Toledo, Ohio 43606 419-471-1973
E-mail: info@xrayhomestudies.com
www.xrayhomestudies.com

UNIT NUMBER 5

FACTORS AFFECTING THE RADIOGRAPHIC IMAGE DETAIL AND DISTORTION

PREPARED BY: Carolyn J. Frigmanski, M.A., B.S.R.T. (R)

INTRODUCTION

This unit will discuss the factors medical radiographers can manipulate to produce images with optimal sharpness of detail. Since sharpness of detail is geometric in nature, we will not be discussing exposure factors since they contribute to the visibility of recorded detail.

As the radiographer critiques each of the final images produced for the examination, he or she must take into consideration the following characteristics. Resolution involves the ability to detect separate and distinct structures within the organ such as the trabecula within bone. Resolution should be high.

Noise is the unwanted, unnecessary densities that we produce on our finished image based predominantly on the graininess of the film selected and the interaction of radiation with our intensifying screen crystals. It is important for radiographers to minimize the level of noise on the finished image so that it does not detract from valuable diagnostic information. Appropriate film/screen speed combinations that let us minimize our dose to the patient but also provide appropriately exposed diagnostic films must be considered. We obviously make compromises every day in our performance of a variety of radiographic examinations.

In reality we may not be able to select a variety of film/screen combinations. Whenever possible, slower or ultra-detail film/screen combinations should be used to enhance detail while faster film/screen combinations should be selected to minimize radiation dose for larger body part examinations. We will discuss these features of film and screen in Unit 7.

Magnification formulas will be reviewed which assist us in determining appropriate image and object size relationships.

DETAIL TERMS

Detail is defined as the sharpness of the often minute structural lines recorded in the radiographic image.[1(p235)] The terms definition, sharpness, resolution, and simply detail have been used previously as synonyms.

I am sure each of us has made "shadow animals" with our fingers when the teacher or our parents turned on a slide or movie projector. When we inserted our hand and curved fingers in the light beam, we were able to create a shadow that was somewhat larger and distorted than our actual hand. Our hand represents the umbra or image proper. The fuzzy, unsharp shadow surrounding the umbra is called the penumbra. When we want to optimize radiographic detail, it is essential for us to optimize the umbra and minimize the penumbra.

Resolution is the ability to see separate objects on a finished radiograph.[1(p254)] Spatial resolution is easily identified when looking at the soft tissue versus bone interface in our skeletal radiographs. X-ray is excellent for high contrast resolution while MRI is excellent for low contrast resolution.

The STAR test pattern is used for evaluating focal spot size.[1(p431)] The STAR test pattern can be easily seen on your television at home if you happen to be up in the wee hours of the morning to see the test pattern. The test pattern is a circle with lines concentrated in the center and radiating outward. The recorded detail is much greater the closer we can see the distinctive lines in the center.

The second test item is called the parallel line type. This particular item is used in evaluating intensifying screens. The parallel line type has a series of parallel lead lines imbedded in a 6" piece of plastic. The lines are closely paired at one end of the test device with millimeters of separation and then continue to greater millimeter separations at the opposite end. We use this horizontal piece of plastic by laying it on top of cassette and then exposing it to radiation. A line pair is considered a lead line and the adjacent space. It is expressed in line pairs/millimeters.[1(p210)] When we produce the image, we look to see which sets of line pairs we can see clearly. Obviously, intensifying screens that have good detail will let us see line pairs in the very smallest millimeter portion of our test device.

BENSON LINE FOCUS PRINCIPLE

The Benson line focus principle describes the geometric principle that occurs at the target on the anode of the x-ray after electron interaction. The actual focal spot is created by the electron stream from the cathode when the kilovoltage is applied.[1(p133)] The effective, apparent, or projected focal spot is the result of the size and angle of the target when the x-ray beam is created and projected to the patient. The projected focal spot is largest when it is nearly perpendicular to the face of the target and smallest when it moves to the anode side of the x-ray beam. This geometric principle allows x-ray tube manufacturers to create a focus in the anode that projects smaller than its actual area on the target. The effective size of the focal spot becomes smaller as the angle becomes steeper or more perpendicular. At routine source image distances, the differences in the sharpness of detail are minimal.

FOCAL SPOT BLUR

Focal spot blur is created by the interaction of electrons from the cathode as they are converted to x-rays at the target on the beveled edge of the anode.[1(p268)] The degree of angulation of the anode can create significant differences in the recorded detail on the image receptor below. It is important for us to select the smallest focal spot whenever practical so that we minimize blur. However, we should consider the fact that smaller focal spot sizes are accompanied by the use of smaller mA selections on our operator consoles. Therefore, it becomes prohibitive for us to use small focal spots on larger body parts based on the concentration of thermal heat in a small focal spot in our x-ray tubes. Most often we will see the focal spot associated to the smaller mA selections (usually below 100 mA) linked by mechanical means. In this manner, we can prevent overloading the smaller focal spot with excessive heat that would be generated by a larger electron stream striking the target if a larger mA selection was made in error.

Important concept: To ***MINIMIZE*** Blur, use a ***SMALL*** focal spot whenever applicable. Smaller focal spot size should be used when detail needs to be maximized. Smaller focal spot sizes are usually accompanied with small mA selections.

OBJECT BLUR

The objects we radiograph most often are anatomic structures. Anatomic structures lie in different planes of our body in addition to having different shapes. When an object has a shape conforming to that of the divergent x-ray beam, all the x-rays will pass through the full thickness of the tissue. This results in a radiographic image with a sharp boundary or density gradient. As x-rays pass through progressively thinner portions of an object toward its periphery, the image density gradually fades out at the border and object blur becomes more apparent. Rounded objects produce less sharp images than rectangular or square objects because of the peripheral density gradient.

SOURCE IMAGE DISTANCE/FOCAL FILM DISTANCE

It is important to select an appropriate distance for the radiographic examination that you are performing in efforts to minimize radiation exposure to the patient. However, if we were not concerned with radiation dose, we can enhance our sharpness of recorded detail by using the longest source image distance feasible.[1(p250)] This phenomenon becomes apparent because x-rays travel more perpendicularly at six feet and provide a less tangential beam to the body part under examination. Penumbra or blur becomes more evident with short source image distances because the tangential lines which represent x-rays are widened as they interact with the body structures before reaching the image receptor.

Important concept: To ***MINIMIZE*** unsharpness, use the longest S.I.D. feasible considering patient dose. Longer focal film/source image distances improve detail, but also increase patient dose.

OBJECT-IMAGE DISTANCE/OBJECT-FILM DISTANCE

Whenever possible, recorded detail can be maximized by keeping the object as close as possible to the image receptor. This can be demonstrated quite easily by placing your hand on the desk and then raising it a couple of inches from the desk surface. You can see a shadow that is now more obvious and more distorted than when your hand was on the table surface. This visual display using light energy photons is synonymous to the images we create using x-ray photons. The principle is exactly the same. The farther the object is away from the image receptor, the less detail will be provided.

Important concept: To ***MINIMIZE*** unsharpness, use the closest object-film/object-image contact possible.

SCREEN FACTOR

It is important to understand two concepts about the interaction of radiation and the crystals within our intensifying screens. One is a factor called noise. Noise is considered to be the unwanted optical density from radiation that impairs our recorded detail.[1(p209)] Let's use the example of the appliance store. When you walk into the store, you may see a wall of various TV models. There are some television models displaying pictures with uneven densities or a snow-like appearance that you did not find esthetically pleasing. This snow-like appearance was created on your television just as it is in our x-ray images by a phenomenon called quantum mottle.[1(p210)] Quantum mottle is the random nature of x-rays as they interact with the screen crystals in our cassettes. Screens that possess large crystals are called fast because they respond with a great deal of light when they are interacted with a x-ray photon. In this manner, we can reduce the dose to the patient, but we do loose recorded detail. We have now created what we call screen blur or unsharpness based on the size of the crystals that we are using in our cassettes and also the thickness of the layer of crystals found in the screen. Bigger crystals in thicker layers will provide faster speeds to reduce the dose to the patient, but we compromise with the loss in recorded detail.

Important concept: To ***MINIMIZE*** unsharpness, use the slowest combination with consideration of patient dose. Slow film/screen combinations will increase sharpness, increase contrast and decrease noise.

FILM FACTORS

There are three primary factors to be considered in the category of film. The first is film graininess. Graininess is the inherent distribution of silver halide crystals in the film emulsion when manufactured by the commercial vendor. Fast film means that the silver halide crystals are large and thereby respond very quickly to light and radiation interacting with it inside the cassette.[1(p185)] Graininess on the finished image becomes much more apparent and less appealing using fast film in comparison to slow film with smaller crystals in thinner layers.

The second factor to consider is whether to use screen film versus non-screen film.[1(pp212-213)] Non-screen film is film that is in a lightproof envelope or a cardboard holder and responds directly to radiation to produce the finished radiograph. Screen film has to be partnered up with one or two screens in a cassette. Detail is always maximized using non-screen film because we do not lose detail based on the layering of screens and the construction of the cassette. However, patient dose is approximately 20 times greater with non-screen film when comparing it to the same body part where a cassette with two screens has been utilized. The patient dose reduction with screen film is significant. 95-98% of the density on a finished radiograph is produced by the light from crystals in the screens and not from radiation. In the selection of our film product, we may have to compromise detail for patient dose reduction.

The last factor to consider is film that can be purchased with an anti-crossover layer. This additional layer in film construction prevents the light that is generated from the front screen crystals from bouncing through the film emulsion to the back screen crystals or constantly crossing over between screen layers and film emulsions. When we can minimize this interaction, we can improve the overall recorded detail of the finished radiograph. It is to our advantage to select film products that possess an anti-crossover layer if recorded detail is to be maximized.

FILM/SCREEN COMBINATIONS

It is important to make educated decisions about the film/screen combinations utilized for radiographic examinations. Obviously, for small body parts, it is to our advantage to use the slowest combination of film and screen in partnership to maximize detail. However, we do have to consider patient radiation dose.[1(p212)] Slow film/screen combination should be restricted to small extremity examinations, foreign body localization, mammography, etc. when dose considerations have been made. Slow film/screen combinations provide the maximum in detail, satisfactory contrast and low noise distraction.

CASSETTES

Cassettes can be damaged in our day to day activities with patients and equipment. Damaged cassettes can create a loss of contact of the film between the screens inside. The area of poor contact is manifested as an area of poor sharpness of detail. It is important to periodically conduct a wire mesh test to evaluate screens for poor contact. This poor contact can be created by warped and damaged hinges, broken latches, warped cassette fronts, excessive body weight that has been placed on the cassette surface directly, etc.[1(p218)] Poor screen contact can be easily identified as areas of loss or unsharp information on finished radiographs. The cassette should be isolated and the wire mesh test conducted on it. The wire mesh is simply a piece of screen, metallic in nature, which is imbedded in clear plastic. It is usually 14" x 17" in size. The wire mesh is taped to the cassette front and a minimal exposure is made to produce the pattern of the wire squares. After development, the film should be evaluated to see if there are areas of unsharp screen patterns by looking at the intersecting perpendicular and horizontal wire strips. In most instances, cassettes or screens that have been damaged need to be replaced. Since both of these items cost a substantial amount of money, it is important for us to use extreme caution with our image receptors so that we can minimize unnecessary expenses in department operation.

DISTORTION

Distortion exists as a misrepresentation of the size and shape of an anatomic structure.[1(p285)] There are actually two categories of distortion. The first is described as productive distortion in which we magnify the size of an object to gain diagnostic information.[1(p286)] For example, magnification views of the navicular bone may be requested because it is important for us to delineate small fractures. Magnification may be necessary to alter the shape of an anatomic structure to gain diagnostic information. Doing a lordotic chest film helps us to eliminate the superimposition of the clavicles in the apex of the lung to rule out tuberculin lesions. These forms of distortion are productive.

The second category of distortion is considered nonproductive. Nonproductive distortion is the magnification or the misrepresentation of the shape of an object that render no diagnostic value.[1(p286)] An example would be doing a portable chest x-ray on a patient in the Fowler's position. If the tube is inappropriately angled, the resultant image would appear somewhat lordotic. You should have been recreating a true AP projection of the chest if the tube angulation had been accurate. Therefore, the portable would need to be repeated because you did not provide any essential diagnostic information on the finished radiograph.

UNAVOIDABLE DISTORTION

Due to the various anatomic structures in our body, we cannot escape distortion to some degree. The causes of distortion relate to the thickness of the anatomic structure and the position of the anatomic structure within our body.[1(pp266-267)] For example, if we look at the femur examination, we note that the head of the femur is surrounded by thicker body tissues in comparison to the distal portion of the femur located at the knee where the thickness is less. We also note that the femur does not lie parallel to the tabletop or the film in the Bucky. This creates a loss of recorded detail at the femoral head and acetabulum portion of the film due to increased object image distance in comparison to the level of recorded detail which is greater at the knee because of its proximity to the film.

Important concept: To minimize distortion, we should make every attempt to keep the tube, film and patient in the same plane whenever possible. When this occurs, distortion is minimized. We can foreshorten (shorter than its real size) or elongate (longer than its real size) an anatomic structure by simply mis-aligning one of these three items or by utilizing an inappropriate tube tilt.

MAGNIFICATION

Magnification and/or its synonym macroradiography has advantages in certain diagnostic radiographic examinations. It is helpful for us to understand how to produce a magnified image with minimal loss of recorded detail. To magnify an anatomic structure, it is necessary to move the object away from the imaging receptor.[1(pp226-265)] It becomes obvious to us that increasing the object image distance creates a loss of detail. To compensate for the loss in detail, we must use two other geometric factors. These include lengthening the source image distance that correspondingly creates a greater radiation dose to the patient. We can select a fractional focal spot that means the tube must possess a focal spot less than 1 mm in size. Having a smaller focal spot allows a less divergent beam to result and thereby minimizes the penumbral blur on the resultant image.

There are several formulas to be used in calculating optimum magnification technique. The first is considered the magnification factor. We are going to compare the image size to the object size.

To calculate a Magnification Factor

$$\text{M.F.} = \frac{\text{Image Size}}{\text{Object Size}} \quad \text{or} \quad \frac{\text{S.I.D.}}{\text{S.O.D.}} \quad \text{or} \quad \text{Object Size} = (\text{Image Size}) \times \frac{\text{S.O.D.}}{\text{S.I.D.}}$$

(source object distance)

For practice, let's calculate magnification factors in the following three examples by dividing the object size into the image size.

$$\text{Magnification Factor} = \frac{\text{Image Size}}{\text{Object Size}}$$

	Image size	Object size	Magnification factor
Situation a.	4"	2"	answer: ___2___
Situation b.	3"	1"	answer: ___3___
Situation c.	6"	4"	answer: __1.5__

Now, let's calculate image size in the following two examples by setting up the problem details in the formula. The formula listed below allows us to calculate the expected image size on the radiograph or the actual object size within the patient.

$$\text{Object size} = (\text{image size}) \times \frac{\text{S.O.D.}}{\text{S.I.D.}}$$

The object size is 5" in width. The S.I.D. was 40" and S.O.D. was 30". What is the image size?

$$\frac{\text{X image size}}{5''} = \frac{40''\ \text{S.I.D.}}{30''\ \text{S.O.D.}}$$

answer: 6.6"

The navicular bone of the wrist measures 2 cm on the radiograph. The S.I.D. is 40" and S.O.D. is estimated at 30". What is the actual size of the navicular?

$$\text{Object size} = 2\ \text{cm} \times \frac{30''}{40''}$$

answer: 1.5 cm is the size of the actual navicular bone.

The last formula allows us to calculate a percentage of magnification with the geometric factors we have selected.

$$\%\ \text{Magnification} = \frac{\text{image width - object width}}{\text{object width}} \times 100$$

Let's calculate the % of magnification for these two situations.

The image width is measured at 3 cm. The object width is 2 cm.

$$50\% = \frac{3\ \text{cm} - 2\ \text{cm}}{2\ \text{cm}} \times 100$$

Here's another practice problem for you. The image width is 5 cm and the object width is 2 cm. What is the % of magnification?

$$150\% = \frac{5 \text{ cm} - 2 \text{ cm}}{2 \text{ cm}} \times 100$$

PATIENT MOTION

Patient motion is the single most detriment to detail on the finished radiograph. There are two types of motion.[1(p272)]

a. Voluntary motion involves the patient who can consciously control it. Examples would be a coherent patient holding still or taking in a deep breath and holding it.
b. Involuntary motion involves the patient who cannot consciously control it. Examples would be peristaltic contractions, cardiac cycles, and other body functions controlled by the autonomic nervous system.

To minimize the risk of patient motion, it is imperative for radiographers to use immobilization devices carefully, provide appropriate assessment of the patient's comprehension of respiratory instructions and to utilize the shortest time of exposure possible.

Important concept: To ***MINIMIZE*** motion unsharpness, be sure the equipment and/or patient does not move during the exposure by locking the tube, securing the film and immobilizing the patient. Use the shortest time selection possible.

This concludes unit 5. Please proceed to the unit questions and complete the required personal data.

Some Important Terms and/or Concepts in Unit 5

Sharpness of detail is geometric in nature.
Visibility of recorded detail is controlled by exposure factors.

Resolution involves the ability to detect separate and distinct structures within the organ such as the trabecula within bone.

Noise is the unwanted, unnecessary densities that we produce on our finished image based predominantly on the graininess of the film selected and the interaction of radiation with our intensifying screen crystals.

Detail

- Sharpness of the often minute structural lines recorded in the radiographic image.
- Umbra or image proper.
- Penumbra is the fuzzy unsharp shadow surrounding the umbra.
- STAR test pattern - used for evaluating focal spot size.
- Parallel line type - used in evaluating intensifying screens.

Benson line focus principle

- Actual focal spot is created by the electron stream from the cathode when the kilovoltage is applied.
- Effective, apparent or projected focal spot is the result of the size and angle of the target when the x-ray beam is created and projected to the patient.

Focal spot blur

- The degree of angulation of the anode can create significant differences in the recorded detail on the image receptor.

Detail

- Always maximized using non-screen film because we do not loose detail based on the layering of screens and the construction of the cassette.
- Patient dose is approximately 20 times greater with non-screen film when comparing it to the same body part where a cassette with two screens has been utilized.
- Anti-crossover layer - additional layer in film construction prevents the light that is generated from the front screen crystals from bouncing through the film emulsion to the back screen crystals or constantly crossing over between screen layers and film emulsions.

Film/screen combinations

- Small body parts - use slowest combination of film and screen in partnership to maximize detail.

Cassettes

- Poor screen contact can be easily identified as areas of loss or unsharp information on finished radiographs.

Distortion

- A misrepresentation of size and shape of an anatomic structure.
- Productive distortion - magnify the size of an object to gain diagnostic information.
- Non-productive distortion - magnification or misrepresentation of the shape of an object that render no diagnostic value.

Magnification

- To magnify an anatomic structure, it is necessary to move the object away from the imaging receptor.

Patient motion is the single most detriment to detail on the finished radiograph.

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[1] Bushong, SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis, MO: Mosby, Inc., 2001.

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P.O. Box 2931 Toledo, Ohio 43606 419-471-1973
E-mail: info@xrayhomestudies.com
www.xrayhomestudies.com

UNIT NUMBER 6

ACCESSORY DEVICES USED IN RADIOGRAPHIC TECHNIQUES

PREPARED BY: Carolyn J. Frigmanski, M.A., B.S.R.T. (R)

INTRODUCTION

In this unit we will discuss accessory devices used in radiographic techniques. Some of these accessories include grids, beam restricting devices, anode heel effect, compensatory filters, etc. We sometimes take these devices for granted and grow careless in their applications in producing quality radiographic images.

UTILIZATION OF GRIDS

A grid is constructed of two sections. The radiopaque material or grid material is usually made of lead alternating with sections of a radiolucent material called the interspace.[1(p233)] The interspace material is usually made of aluminum or plastic. The primary function of the grid is to clean up scatter radiation. The grid will only allow those x-rays that are most perpendicular after exiting the patient to reach the film. The scatter radiation that is produced and travelling in an oblique direction will be absorbed by the lead strips.

Grids are recommended on anatomic body parts greater than10-12 cm in thickness. It is important to use them wisely because grids do not reduce patient dose. Grids are necessary to minimize scatter/secondary radiation and to optimize diagnostic information.

TYPES OF GRIDS

The types of grids are described by their construction and orientation of lead strips in their longitudinal axis. The first grid to be considered is a linear or parallel grid in which the lead strips are arranged parallel to each other.[1(p237)] A focused grid means the lead strips are canted, i.e. placed perpendicularly in the center and then angled diagonally to correspond to the divergence of the x-ray beam. A crosshatch or cross grid involves two sets of lead strips arranged perpendicularly to one another. This type of grid was first designed by Hollis Potter and Gustav Bucky.

A stationary grid is any grid not associated with a moving device applied to it. Examples are grids attached to cassettes, grid cassettes or grids placed in an upright film holder. A moving grid is a stationary grid that has motor attached to it to allow movement during exposure and thereby reduce the visibility of grid lines on the finished radiograph.[1(p239)] There are a variety of motors that can be purchased to accommodate grid movement.

The advantages of a moving grid involve the removal of grid lines, increasing contrast and sharpness of detail, and reducing fog due to scatter radiation.[1(p239)]

The disadvantages of a moving grid involves increased magnification and geometric unsharpness due to vibration.[1(p239)] They are expensive depending on the type of motor attached to it. They are subject to failure. Utilizing a grid requires an increase patient dose. The increase in patient dose may be reflected by an increase in exposure time that represents a risk for patient motion.

BUCKY MECHANISMS

In 1913 Gustav Bucky introduced the stationary grid and in 1920 Dr. Hollis Potter introduced the mechanism to move the grid to prevent grid lines.

A reciprocating Potter-Bucky mechanism osculates continually during the exposure. It moves forward in 0.3 second and returns at 1.7 seconds. Minimum exposure time is 1/20 second when a reciprocating bucky is used.[2(p319)]

A recipromatic Potter-Bucky mechanism has equal speed for both directions and times may be as short as 1/60 second.[2(p319)]

The oscillating or trill Potter-Bucky mechanism is the most advanced and allows exposure times less than 1/60 second. The grid oscillates or vibrates in a changing position in relation to the bursts of x-ray protons throughout the exposure time.

PHYSICAL FACTORS OF GRID CONSTRUCTION

There are several factors that must be considered when purchasing a grid. The first factor is called the grid ratio.[1(p233)] The grid ratio is defined as a ratio of the height of the lead strip to the distance between them by the interspace material. Grid ratios are usually indicated by a number. For example, 8:1 indicates an 8 to 1 grid that identifies the height of lead strip as 8 times greater than the distance between it and the next lead strip. The smallest grid ratio is a 5:1 and the greatest is a 16:1 grid ratio. The 5:1 grid ratio has less lead content than the 16:1 grid ratio. An increase in exposure for the 5:1 grid ratio is less than the increase needed when a 16:1 grid ratio is utilized.

Another factor to consider is grid frequency.[1(p234)] It represents the number of lead strips per inch or centimeter. Grid lines become less obvious as the grid frequency increases. Most grid frequencies occur in the range of 60-100 lines per inch (25-45 lines per centimeter). Grids used in mammography have ratios of 2:1 or 4:1 with grid frequencies of approximately 200 lines per inch (80 lines per centimeter).

Another factor to consider is the contrast improvement factor.[1(p235)] It is simply a ratio of the contrast of a finished radiograph made with the grid to the contrast of a radiograph made without the grid.

$$K = \frac{\text{contrast with the grid}}{\text{contrast without the grid}}$$

The contrast improvement factor is usually measured at 100 kVp.[1(p235)] The K or contrast improvement factor improves as grid ratios increase. A contrast improvement factor of one indicates no change. Most grids have contrast improvement factors that range from 1.5 to 2.5. These numbers indicate the improvements in radiographic contrast when grids are utilized.

Another factor to consider is selectivity.[1(pp236-237)] It is a factor that allows us to evaluate the grid performance. Selectivity is calculated on the amount of primary radiation that reaches the film after passing through the grid. It is a ratio in comparing the primary radiation and the scatter radiation that is absorbed. The total lead content of the grid and the grid ratio play a significant part in the selectivity of the grid. Higher grid ratios have greater selectivity because the lead strips are closer together and the primary or scatter radiation must be perpendicular or a few degrees off the axis to reach the film. Because the grid absorbs this primary and scatter radiation that is not perpendicular or a few degrees off the axis, the contrast is improved on the finished radiograph. Selectivity increases attenuation and decreases scatter. Because of these influences, patient dose must be increased.

The last factor to consider is the Bucky factor.[1(p236)] It is a ratio of the incident radiation falling on the grid in comparison to the remnant radiation after the grid. It is used to measure the penetration of both primary and scatter radiation when a grid is utilized. The Bucky factor increases with higher kV, increased grid ratio and increased mAs. Increasing all of these factors warrant an increase in patient dose.

GRID CUTOFF

Grid cutoff is the uneven density or loss of density on the resultant image due to the undesirable absorption of the primary x-ray beam by the grid.[1(p237)] Grid cutoff occurs when grids are not utilized in the appropriate manner. There are four situations that promote grid cutoff. Radiographers should be conscientious of these four situations so that they can minimize the risk of creating cutoff.

The selected grid for a procedure must lie in a plane perpendicular to the central access of the x-ray beam.[1(p240)] If the grid is tilted and no longer perpendicular to the central ray, an off-level grid error will be produced. The entire radiograph will appear uniformly under-exposed because the primary beam has been absorbed by the lead strips before reaching the film. The possibility of off level grid errors is significant when performing portable radiography with a grid. It is important to have even distribution of the patient's body weight on the grid so that the grid is not tilted.

An off-center error occurs when the grid is tilted and it is no longer parallel to the patient or the perpendicular to the x-ray tube.[1(p241)] This problem can occur when the x-ray tube is not locked to the center of the table when the Bucky is utilized.

An off-focus error involves the incorrect utilization of distance for a focused grid.[1(p241)] The grid manufacturer will provide important details on the recommended focusing distance to be used with the particular grid. The convergent point or line is an imaginary place in space above the focused grid that reflects the centralized point where the canted lead lines intersect. The convergent point may be 40 inches with an allowance of 10% for acceptable use. In other words the focusing distance for grid may be 36-44 inches. Grids used closer or farther than these recommended distances will create grid cutoff on the periphery of the film.

Grids have the tube side identified on their surface. It is important to utilize the grid with the correct side to the tube. Density will only result in the center where the lead strips are perpendicular to the central ray if the grid is used upside down.[1(pp241-242)] Grid cutoff on the periphery of the film will be maximized because the radiation will be absorbed by the walls of the lead strips located within the grid.

EXPOSURES CORRECTION FOR GRIDS

The table listed below provides the recommended corrections for various grid ratios.[1(p243)] Corrections with changes in grid ratio can be accomplished by utilizing kilovoltage. However, it must be remembered that kilovoltage affects the overall scale of contrast. In most instances, it is not the preferred recommendation because the kilovoltage adjustments may be as high as 20-25 kVp.

5:1 ratio = 2 x non-grid mAs or +8 kVp

Adjusting kVp changes the scale of contrast.

6:1 ratio = 3 x non-grid mAs or +10 kVp
8:1 ratio = 4 x non-grid mAs or +15 kVp
10 or 12:1 ratio = 5 x non-grid mAs or +20-25 kVp
16:1 ratio = 6 x non-grid mAs or +20-25 kVp

We will discuss various ways to apply the information on the table. For example, 10 mAs is used non-grid. A 10:1 grid ratio has been selected. The technique must be increased to accommodate the physical factors of the grid construction. Utilizing the table, we note that a 5 x non-grid mAs must be used with a 10:1 grid ratio. Therefore, the new technique with the 10:1 grid ratio will be 50 mAs.

We can also correct exposure factors when switching from grid to non-grid. For example, let's say a 6:1 grid ratio was used with an original exposure of 30 mAs. A non-grid correction must be calculated. On utilizing the table, we note that the grid conversion factor is 3 for 6:1 grid. If we divide 3 into 30 mAs, the non-grid mAs correction will be 10 mAs.

We can also make corrections when changing from one grid ratio to another. Let's use the example of a 5:1 grid ratio that was used with 20 mAs as the original exposure. The grid was then changed to a 8:1. The table tells us that a 5:1 grid ratio is 2 x non-grid. Therefore if we divide 2 into 20 mAs, we will be able to determine that the non-grid mAs is 10. The 8:1 grid ratio on the table indicates a factor of 4 x the non-grid mAs. We had established a non-grid mAs of 10 so that if we multiply by 4, the correction for the 8:1 grid ratio change is 40 mAs.

I have included several practice problems for you to do in calculating grid changes.

1. An 8:1 grid was used with 40 mAs. What mAs would be used non-grid?

8:1 = 4 x non-grid

Answer: $\frac{40 \text{ mAs}}{4} = 10 \text{ mAs}$

40 mAs = 4 x _____ mAs

Let's calculate the next three problems.

2.

FROM	TO	ANSWER
120 mAs 16:1	_____ mAs non-grid	$\frac{120 \text{ mAs}}{6} = 20 \text{ mAs}$
30 mAs non-grid	_____ mAs 12:1	12:1 = 5 x 30 mAs = 150 mAs
60 mAs 10:1	_____ mAs 6:1	10:1 60 mAs = 5 x non-grid $\frac{60}{5}$ = 12 mAs as non-grid 6:1 = 3 x non-grid 6:1 = 3 x 12 mAs 6:1 requires 36 mAs

GRIDS AND PATIENT DOSE

The recommended grid ratios in diagnostic radiography are 8:1 when filming below 90 kVp and a 10 or 12:1 grid ratio is recommended for examination requiring kilovoltage ranges greater than 90 kVp.[1(p243)] It is important to realize that higher grid ratios indicate higher patient doses with better clean up of scatter radiation.

AIR GAP TECHNIQUE

Air gap requires us to increase object distance to the film to create an alternative method to a grid.[1(p244)] The scatter radiation will not interact with the film surface to the same degree it would if the patient was adjacent to the film. Using an air gap requires an increased source image distance to compensate for the loss of detail by the purposeful object image distance. Patient exposure must be increased. Therefore, the air gap technique is not utilized in clinical practice to any great extent.

Increasing object image distance allows less scatter to reach the film and contrasts improves. Air gap technique is used predominantly for chest radiography, cervical spine radiography and cerebral arteriography. However, it may be utilized any time magnification views are requested.

BEAM-RESTRICTING DEVICES

Any device used to restrict the primary beam will correspondingly reduce the amount of secondary radiation that is helpful in providing density to the overall image.[1(p225)] When we restrict the primary beam, we reduce the overall density on the image. We must compensate with our primary exposure factors initially to provide adequate density. The functions of beam-restricting devices are to protect the patient because the smaller the x-ray field, the smaller the area of patient exposure. By decreasing scatter radiation contrast improves.

APERTURES

The first device is called an aperture or diaphragm.[1(pp225-227)] It operates in a manner similar to the lens of a camera or the pupil of the eye. It is composed of inter-leaving lead plates that can expand and contract in a circular size to allow more or less primary radiation to exit from the x-ray tube housing.

TO CALCULATE APERTURES:

$$\frac{\text{focus-to-aperture distance}}{\text{S.I.D./F.F.D.}} = \frac{\text{aperture diameter}}{\text{film diameter or projected diameter}}$$

Here are the problems:

1. What is the size of the projected area for an aperture that is 1" in diameter with a 4" focus-to-aperture distance at a 40" focal film distance/S.I.D.?

$$\frac{\text{4" focus-to-aperture distance}}{\text{40" S.I.D./F.F.D.}} = \frac{\text{1" aperture diameter}}{\text{X film size or projected diameter}}$$

$$X = 10"$$

2. What is the size of the projected area for an aperture that is 2.5" diameter with a 6" focus-to-aperture distance at 36" focal film distance/S.I.D.?

$$\frac{\text{6" focus-to-aperture distance}}{\text{36" S.I.D./F.F.D.}} = \frac{\text{2.5" aperture diameter}}{X}$$

X = 15" film size or projected diameter

CONES AND CYLINDERS

The second device is a cone that is attached to the x-ray tube.[1(p227)] Cones come in various diameters and lengths. Cones can reduce the primary radiation field size based on the measurements of the selected cone.

When a cylinder cone was attached to the tube, the exposure factors had to be increased to compensate for the loss of scatter radiation that contributed to film density due to the small field size.[1(p227)] Some cones could also be lengthened in telescoping manner.

TO CALCULATE CONE COVERAGE:

$$\frac{\text{film coverage diameter}}{\text{cylinder diameter}} = \frac{\text{F.F.D./S.I.D.}}{\text{focus to lower aperture distance and cone length}}$$

Here are the problems:

1. What is the size of the projected area for a cylinder cone that is 10 inches in length, 6" in diameter, at 40" S.I.D., if the focus-to-attachment distance of the cone is 3"?

$$\frac{\text{X film coverage area/projected area}}{\text{6"}} = \frac{\text{40" S.I.D./F.F.D.}}{\text{13" focus-to-lower aperture distance and cone length}}$$

X = 18"

2. What is the size of the projected area for a cylinder cone that is 12" in length, 8" in diameter, at 36" S.I.D., if the focus-to-attachment distance of cone is 4"?

$$\frac{\text{X film coverage area/projected area}}{\text{8"}} = \frac{\text{36" S.I.D./F.F.D.}}{\text{16" focus-to-lower aperture distance and cone length}}$$

X = 18"

Primary exposure factors were adjusted as follows:
Half extended = increase 40-60%
Fully extended = increase 100%

VARIABLE APERTURE COLLIMATORS

The third type of beam-restricting device is the collimator that comes in two varieties.[1(p229)] Manual collimator allows us to manipulate the dimensions of the beam size by hand. An automatic collimator will restrict the beam size when a cassette is placed in the bucky tray and the microswitches are activated.

Let's discuss manual collimators first. Manual collimators have two sets of shutters, and upper and a lower that are located in the collimator housing.[1(p229)] These work in a partnership arrangement to reduce the beam size in both directions. It is necessary for us to keep the field size the same or less than the size of the anatomic part under examination when diagnostic information is not jeopardized. It is never appropriate to open the beam size larger than the anatomic part under examination and the film size selected. Automatic collimators operate on micro-switches that are located in the back portion of the bucky tray that holds the cassette. When the film is locked in position in the bucky tray and inserted into the table, micro-switches will be triggered to restrict the pair of lead leaves in the collimator to correspond to the size of film located in the bucky. This positive beam limiting type or automatic collimator reduces the possibilities of radiographers exposing more tissue than absolutely necessary. However, in some examinations, it may necessary to collimate smaller than the film size. It is important for positive beam limiting type collimators to have a manual override so that radiographers can reduce the field size when necessary.

ANODE HEEL EFFECT

There is a variation in the intensity of the primary beam as it exits the x-ray tube due to the beveled edge of the anode.[1(pp132-133)] The beam is less intense on the anode end of the tube and more intense at the cathode end of the tube. The central ray (the most perpendicular portion of the beam) has an intensity of 100%. Since more of the x-ray beam will be deflected to the cathode portion of the tube, the intensity will range between 105 or 110%. By the same token, if we measure the intensity of the beam at the anode end, we will find that the intensity ranges between 75-95%. It is important for us to remember to keep the thinner portion of the patient's body part to the anode of the tube and the thicker portion of the patient's body part to the cathode end of the tube. In this manner we can provide a more uniform density on our resultant images of body parts of varying thicknesses. All x-ray tubes have their anodes and cathodes identified either by a full name or +/- symbol. The anode is the positive terminal and the cathode is the negative terminal. You can accomplish this principle by simply turning the tube to the correct alignment of the patient's body part or reversing the patient's position on the table for certain examinations.

COMPENSATORY FILTERS

We historically have used compensatory filters to a greater degree than what we use today. These are filters added to the beam that are specifically designed to accommodate varying body thicknesses and tissue densities. When the filter is used appropriately, we can provide a more uniform density on the film. Several names for compensatory filters include wedge, trough and commercial models for specific use.

An example of a wedge filter is a triangular piece of metal that is inserted in the tube housing with the thick end of the filter at the thinnest end of the body and the thin end of the filter at the thicker portion.[1(p161)] If we are using a wedge filter on an AP dorsal spine projection, we would have the cervical portion of the patient's body at the thick portion of the filter and the lower dorsal/lumbar portion of the patient's body at the thinner portion of the filter. In this manner we can eliminate the added blackness at the cervical area and produce a better-exposed AP dorsal spine.

A second type of compensatory filter, commonly used in chest radiography, is the trough filter.[1(pp161-162)] It has a thinner central portion and thicker peripheral portions. The trough filter will allow greater penetration and density through the mediastinum. The thicker portions of the filter on the periphery will prevent the lung tissue from being burned out or too dense for appropriate visualization of the bronchovascular markings.

BLACK PAPER TECHNIQUE

Years ago it was common practice for film manufacturers to have a black interleaving paper between sheets of film in the cartons. This black piece of paper could be utilized in performing examinations on body parts of varying thicknesses. For example, if a black sheet of paper was cut in half and placed in the bottom portion of a 14" x 17" cassette, we could produce a better exposed AP pelvimetry film because the black paper in the bottom portion of the cassette would prohibit the crystals from fluorescencing and thereby reduce the density over the lower pelvic area. The only problem with using the black paper technique was that the radiographer had to properly place the black paper in the cassette in relation to the thinner body. The black paper found in the film cartons was manufactured with a high quality paper so that it did no produce unwanted artifacts on the resultant images.

VIEWING CONDITIONS

Diagnostic radiographs possessing sharpness and visibility of detail with an appropriate scale of contrast can be optimized when they are illuminated by light of a conventional color and brightness on a view box. A view box is also referred to an illuminator. The radiographer and the radiologist should be viewing the finished radiographs on view boxes emitting equivalent color and intensity of light.

Photometry is defined as the science of the measurement of light. The Systems International photometric units we will use are the NIT for luminance and the LUX for illuminance. Luminance is defined as the amount of light either scattered or emitted by a surface. A NIT is calculated as candela/m2. Illuminance is defined as the amount of light falling on a surface. A LUX is calculated as lumen/m2. Sufficient luminance must be provided by our view boxes so that the density range of interest can be visualized. A typical view box luminance of 1,500 NIT will allow us to visualize a maximum density of 2.8. Brighter view boxes of 3-7,000 NIT will allow us to visualize a maximum density of 3.1-3.4. General diagnostic films contain details at densities up to 3.5. Please refer to the chart at the conclusion of this unit for reference.

The life expectancy of fluorescent lamps is 20,000 hours or 2,500 days for eight hours a day or 10 years with 250 working days per year based on manufacturer data. View box luminance usually decreases 12-18% in just eight months' time. Luminance quality may vary on the view box surface. Luminance values are much lower within 1-2 inches on the edge of the view box. The spectrum or color of the view box light affects film interpretation conditions. The color temperature of a view box may be affected by the type of fluorescent lamps used, the tint of the reflective interior of the view box and the transmission of light through the opal diffusers used as the front of the view box.

View boxes should be positioned to avoid light from windows, other view boxes, and any other sources of bright light that can be direct or reflected.

To obtain the best light transmission through the radiograph, the light surrounding the film size should be blocked out. This unwanted surrounding light is commonly called ambient lighting. A mask of black paper or other dense material should be used to reduce ambient light. Some mechanical devices operate on an aperture principle to open and close the volume of acceptable light reaching the film. Some masks have permanent sizes and come in an assortment of shapes and dimensions. Too much ambient light can make the density on the finished radiograph seem greater than it is in reality. This situation occurs because the extraneous light causes the pupil of the viewer's eyes to contract. This contraction makes it more difficult to adjust to the transmitted light through the film. The level of general lighting in the interpretation area should be low enough to reduce glare on the finished film surface.

View boxes should have their external surfaces cleaned regularly. The opal diffusing glass should be cleaned with a mild soap and water with drying so that residue does not exist.

The fluorescent tubes should be checked for consistent light output particularly when one view box in a series has had fluorescent tubes replaced. The fluorescent tubes may be long and situated parallel to each other in the view box or they may be circular in nature.

One of the routine quality control procedures that should be adopted in most departments is to evaluate the view box light emission in all areas and then take action to convert them to an established parameter. This may seem unreasonable based on the number in view box installations. Parameters should be established for dedicated radiographic installations in which specific examinations are performed, i.e. dedicated view boxes or a viewing system may be necessary for mammography images only. If a facility owns multiple alternators and/or viewing machines, it is important that the alternator have consistent light emission so that the multiple images "hung" on these panels will not be degraded in quality.

This concludes unit 6. Please proceed to the unit questions and complete the required personal data.

S★T★A★R★S

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P.O. Box 2931 Toledo, Ohio 43606
Phone: 419-471-1973
Website: www.xrayhomestudies.com

Typical Illuminance Values Measured in Lux for Reference

10^5	**Direct Sunlight Conditions**
10^4	**Full Daylight Conditions**
10^3	**Overcast Daylight Conditions**
10^2	**Very Dark Daylight Conditions**
10^1	**Twilight Hour Conditions**
10^0	**Deep Twilight Hour Conditions**
10^{-1}	**Full Moon Evening/Night Conditions**
10^{-2}	**Quarter Moon Evening/Night Conditions**
10^{-3}	**Starlight Conditions**
10^{-4}	**Overcast Night Conditions**

****Typical Office Illumination = 75 - 120 Lux**

****Typical/Recommended Reading Room Illumination = 2 - 25 Lux**

Some Important Terms and/or Concepts in Unit 6

GRIDS

- Recommended on anatomic body parts greater than10-12 cm in thickness
- A focused grid means the lead strips are canted, i.e. placed perpendicularly in the center and then angled diagonally to correspond to the divergence of the x-ray beam.
- A crosshatch or cross grid involves two sets of lead strips arranged perpendicularly to one another.
- A stationary grid is any grid not associated with a moving device applied to it.
- A moving grid is a stationary grid that has motor attached to it to allow movement during exposure and thereby reduce the visibility of grid lines on the finished radiograph.

GRID RATIO

- a ratio of the height of the lead strip to the distance between them by the interspace material.

GRID FREQUENCY

- The number of lead strips per inch or centimeter.

CONTRAST IMPROVEMENT FACTOR

- Ratio of the contrast of a finished radiograph made with the grid when compared to the contrast of a radiograph made without the grid.

BUCKY FACTOR

- Ratio of the incident radiation falling on the grid in comparison to the remnant radiation after the grid.

GRID CUTOFF

- Uneven density or loss of density on the resultant image due to undesirable absorption of the primary x-ray beam by the grid.

GRID RATIOS

- Recommended 8:1 when filming below 90 kVp and a 10 or 12:1 grid ratio is recommended for examination requiring kilovoltage ranges greater than 90 kVp.

AIR GAP

- Requires us to increase object distance to the film to create an alternative method to a grid.

BEAM RESTRICTING

- Any device used to restrict the primary beam will correspondingly reduce the amount of secondary radiation that is helpful in providing density to the overall image.

ANODE HEEL EFFECT

- There is a variation in the intensity of the primary beam as it exits the x-ray tube due to the beveled edge of the anode. The beam is less intense on the anode end of the tube and more intense at the cathode end of the tube.

COMPENSATORY FILTERS

- Filters added to the beam are specifically designed to accommodate varying body thicknesses and tissue densities.

PHOTOMETRY

- The science of the measurement of light.

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[1] Bushong, SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis, MO: Mosby, Inc., 2001.
[2] Selman, J. *The Fundamentals of X-ray and Radium Physics.* 4th ed. Springfield, IL: Charles C. Thomas, 1970.

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E-mail: info@xrayhomestudies.com
www.xrayhomestudies.com

UNIT NUMBER __7__

RADIOGRAPHIC FILM, DARKROOM PROCESSING AND INTENSIFYING SCREENS

PREPARED BY: Carolyn J. Frigmanski, M.A., B.S.R.T. (R)

INTRODUCTION

In this unit we will start out with a discussion on x-ray film and its properties. We will follow up with x-ray film processing in both manual and automatic systems and conclude this unit with a discussion on screens and their characteristics.

HISTORICAL DEVELOPMENT OF PHOTOGRAPHIC AND X-RAY FILM

Since there are so many correlations to the principles of photography and radiography, I have included a short historical prospective on the development of both media for your appreciation.

I. History
   A. Early history of photographic film:
      1. 1802 — silhouettes on glass recorded by contact printing on paper coated with silver chloride. Images were transient.
      2. 1816 — film used in camera produced transient negative image.
      3. 1839 — basis for chemical development of photo-sensitive materials was established.
      4. 1840 — negative positive photography established
      5. 1847 — paper negatives used until 1847. Glass plates coated with albumen emulsion was introduced.
      6. 1851 — wet collodion glass plates were invented.
      7. 1871 — dry gelatin glass plates were invented.
      8. 1879 — mechanically coated gelatin glass plates were invented.
      9. 1885 — stripping film with paper emulsion support was incorporated.
      10. 1889 — cellulose nitrate emulsion support was incorporated.
      11. 1890 — science of photographic sensitometry by Hurter and Driffield was developed.

B. Early history of radiographic film:

1. 1895 - photographic glass plates were used.
2. 1914 - single coated cellulose nitrate films were developed. Fire hazards became prominent.
3. 1918 - duplitized film was introduced.
4. 1924 - cellulose acetate film base was introduced.
5. 1933 - tinted film base to enhance contrast was introduced.
6. 1936 - direct exposure film was invented.
7. 1940 - film suitable for both direct and indirect exposure became available on the market.
8. 1958 - fast light sensitive film became available on the market.
9. 1960's - polyester base and films for rapid processing became available on the market.
10. 1978 - low image diffusion x-ray film became available on the market.

RADIOGRAPHIC FILM CONSTRUCTION

The first layer on radiographic film that comes in contact with our hands is the super protective coating that prevents scratches and interruption to the emulsion layer.[1(p181)] The next layer is the emulsion layer. It is the most important and essential layer in the production of our radiographs. The emulsion is composed of gelatinous material extracted from calfskin and refined to a purer state than the gelatin we consume. The second component of the emulsion is microscopic silver halide crystals that have a sensitivity speck made of silver sulfide incorporated in each crystalline particle. One of the choices for a silver halide crystal is silver bromide. This crystal is manufactured by a reaction involving silver and nitric acid to produce silver nitrate. The silver nitrate and the potassium bromide are chemically combined to form the silver bromide crystal that responds to light or radiation. The silver halide crystals are added to the gelatin to produce the emulsion layer. The emulsion layer then has to be applied to the base by an adhesive layer. The structural support for the emulsion is provided by the film base. The film base is manufactured by mixing cotton with acidic acid to form cellulose acetate in solution. The cellulose acetate is refined to provide us a film base that may or may not have the introduction of a dye.[1(p182)] The purpose in adding a dye to the film base is to provide a more esthetically pleasing color to reduce fatigue to the eye by prolonged viewing and to add some density in the lower region of the sensitometric curve. The film base has a sub-coating to adhere the emulsion. Our final product is then an x-ray film. Cellulose acetate bases have been replaced by polyester plastic in the 1960's. When an x-ray film has an emulsion on both sides, it is called duplitized. It is important to use duplitized film in cassettes with two screens. If we are using a single sided film with emulsion, it must be placed in proper correlation to a cassette with a single screen.

TYPES OF RADIOGRAPHIC FILM

There are multiple types of radiographic film on the market to meet specific needs. Below is a listing of the major categories for film selection based on their application in producing and optimizing radiographic imaging modalities.

1. Screen =
   One Emulsion or
   Two Emulsions (duplitized)
2. Mammography
3. Industrial
4. Duplication
5. Subtraction
6. Videorecording
7. Cineradiography
8. Dental
9. Non-Screen
10. Laser

CHARACTERISTICS OF RADIOGRAPHIC FILM

All radiographic films have certain common characteristics. However, the degree to which the characteristic is evident determines the quality and function of the film in its application. The first characteristic is speed or sensitivity that describes the ability of the film to respond to light or radiation.[1(p185)] Film speed or sensitivity is described as slow, par or average or fast or high-speed. We also have ultra-detail speed film that is used in small extremity or foreign body localization applications. The speed or sensitivity of the film correlates to the size of silver halide crystals in the emulsion, the thickness of the layer of silver halide crystals, and the concentration of crystals. Film categorized as slow-speed has small crystals in thin layers that responds slowly to radiation. Film in the fast or high-speed category has larger crystals in thicker layers that responds quickly to radiation. Due to the physical structure of the film, detail may or may not be enhanced. Slow film with thin layers of small crystals provides a greater degree of detail than film possessing larger grains in thicker layers.

The second characteristic is film contrast that is provided by the manufacturer and is inherent in the film emulsion. The choice of films should be determined by the application of the film in specific radiographic examinations.[1(p185)] For example, a film possessing a short scale of contrast may be preferred in examinations of extremities and in angiography, while films possessing a longer scale of contrast may be more desirable in abdominal examinations.

The third characteristic is latitude that provides the radiographer an opportunity to make an error in exposure factor calculations and still render an acceptable image.[1(p185)] Films that are very forgiving are referred to as possessing wide latitude. Films that are very critical with minimal exposure error are considered narrow. Therefore, this quality should be considered when multiple individuals will be utilizing the film in performing a wide variety of examinations such as a teaching institution. A narrow latitude may be better utilized in a facility where there are a limited number of radiographers performing a dedicated procedure, i.e. podiatric applications.

The last factor to consider when selecting the appropriate radiographic film is crossover.[1(pp185-186)] Crossover occurs when light or radiation enters the cassette and activates the crystal in the front screen. These light and radiation photons pass through the film and create light by the black screen. This process creates light and radiation bouncing between screens and through film emulsions. Because of this interaction, some film manufacturers have provided an anti-crossover layer that minimizes the constant transmission of light repeatedly through the film. Obviously, a film possessing an anti-crossover layer provides greater detail. A film may also have a dye added to the base to make it more appealing and provide some density at the toe portion of the sensitometric curve.

RECOMMENDATIONS FOR FILM STORAGE AND HANDLING

It is important for radiographers to store and handle film appropriately to minimize the production of artifacts and unwanted densities that could result in disposal of an expensive and essential supply.[1(p190)] Radiographers should be careful not to bend, crease or rough-handle film when opening boxes, loading and unloading cassettes, and handling the film after processing. Film should be stored at approximately 68 degrees F or 20 degrees C with a 40-60% humidity factor. Unexposed film as well as exposed film should be handled under appropriate lighting conditions. Film should always be stored away from radiation risks. The expiration date provided by the manufacturer should be monitored. It is important to utilize the film within the expiration time. It is not recommended to use film after the expiration date because an age fog may be present as an unwanted density if used in performing examinations.

RECOMMENDATIONS FOR X-RAY FILM IN THE RADIOLOGY DEPARTMENT

Radiographic film should not be stored near sources of x- or gamma rays or devices producing heat such as radiators, vents, and steam pipes or near chemical mixing areas.[1(p190)] Stock rotation should be adhered to on a first-in and first-out basis to minimize risk of expiration date losses. Inventories of various film sizes should be kept at a minimum requirement level. Film boxes should be stored in a vertical position to eliminate pressure fog. Films stored in film bins should be protected from light leaks and high temperature conditions. When film is removed from the storage location, it should be delivered immediately to the area of use and not left in halls, corridors, or other environments that are not appropriate. The delivery of film from storage areas should be made with care to prevent damage to the cartons or undue pressure by dropping. Hospital warehouse and service personnel should be advised about the proper procedures and recommendations for handling x-ray film. The storage area for radiographic film should be checked periodically to make certain that recommended conditions are being maintained and monitored. Radiographers should make every effort to minimize any risk of physical damage or artifact production on film so that radiographic quality will not be jeopardized.

RECOMMENDATIONS FOR FILM WAREHOUSING

As we have already mentioned, it is important to store x-ray film boxes in the upright position and at recommended temperature and humidity. Cases of film should not be stacked on pallet loads on top of each other. The cases of radiographic film should not be left on loading platforms or other areas where it could be exposed to sun, rain, or other harmful weather conditions. Radiographic film should not be stored in areas where it may be damaged or at risk by trucks or other vehicles. The pallets used for warehousing film should be elevated at least 2" from the floor to prevent any risk of water damage. Warehouse personnel should be advised that radiographic film is a perishable product and should be handled with care.

RECOMMENDATION FOR TRANSPORTATION

As we have previously mentioned, special care and handling should be given to x-ray film because it is a perishable product and time should be spent with the delivery personnel so that they are conscientious of this requirement. In geographic areas where high temperature and humidity are prevalent, radiographic film should be transported in air-conditioned carriers.[1(p190)] Cases of film should be secured to prevent damage from movement during transportation. Trucks loaded with radiographic film should not left on loading docks or areas where film may be exposed to weather conditions. The delivery vehicle should be a closed carrier.

EXPOSURE COMPENSATION FOR VARIOUS FILM SPEEDS

Since we have a large selection of film speeds available on the market, it is important for radiographers to be able to calculate appropriate exposure factors when film speeds have been altered.[1(p187)] Par or medium speed film is the standard of reference and has a value of 1. Ultra-detail (U.D.)/slow film speed requires two to three times **MORE** exposure than par or medium speed. Fast or high-speed film requires a 50-75% reduction in exposure when compared to par.

Par film was used with an exposure of 20 mAs and 60 kVp. What new mAs would be used with slow film? Our speed conversion factor from par to slow is two to three times. Slow film will require more exposure because the crystals are smaller in thinner layers. Therefore, the new mAs in this situation would be calculated as follows.

20 mAs x 2 = 40 mAs or 20 mAs x 3 = 60 mAs	40 or 60 mAs would require to produce the same density on the slow film.

I have provided three problems for you to solve with answers provided as a practice exercise.

Original film speed and mAs is changed

From:	To:	Answer:
100 mAs Par	_______ mAs Fast	25-30 mAs
10 mAs Fast	_______ mAs Par	20 mAs
60 mAs Slow (convert to Par =20-30 mAs)	_______ mAs Fast	10-15 mAs

SPECTRAL MATCHING

When utilizing film in a cassette, it is important to load cassettes with film whose sensitivity to light from the screen is properly matched. There are two types of film available on the market today. We have blue-sensitive and green-sensitive (called orthochromatic) film.[1(p187)] Photographic film is considered panchromatic because it is sensitive to all colors.

Blue sensitive film should be partnered up with blue-light emitting screen crystals. Green sensitive film should be partnered up with green-light emitting screen crystals.

TERMS FOR IMAGES

The finished radiograph is actually created by a photoelectrical process as radiation leaves the x-ray tube to pass through the patient and reach the imaging receptor. The invisible image that is created by the silver halide crystals during exposure to light and radiation is termed latent. When the exposed film is being processed, a photochemical interaction occurs because the chemicals in the processing solutions must convert the exposed silver halide crystals to metallic silver. Only the exposed silver halide crystals interacted by photons of light or radiation will be converted. The image that is visibly produced after processing has occurred is described as the manifest image.

A SYNOPSIZED HISTORY OF FILM PROCESSING

1942 - Pako introduced the first automatic film processor on the market with a capacity of processing120 films per hour.
1956 - Eastman Kodak developed a tank and film roller transport system that was enclosed in a processing unit ten feet long and 3/4 ton in weight.
1965 - Eastman Kodak marketed the 90 second processor that has a capacity of processing 215 films per hour.
1987 - Konica introduced 45 second processing with a special chemistry and film partnership.
21st Century - "filmless society" concept will become a reality!

A comparison of manual and automatic processing (chemistry and techniques) is provided on the next three pages for your convenience.

RADIOGRAPHIC FILM DEVELOPING

The primary purpose of film development is to convert the exposed silver halide crystals to metallic silver.[1(p195)] This process can be completed in either a manual or automatic system. I have created a chart that describes the chemicals found in both manual and automatic developer and their respective functions. Developing time in manual systems involve five minutes at 70 degrees Fahrenheit.[1(p193)] Automatic developing takes approximately 22 seconds of immersion in the developing solutions that are maintained at 86-96 degrees Fahrenheit. In manual processing, the film had to be agitated by moving the film so that the chemicals could be evenly distributed on the emulsion surface. In automatic processing, the roller transport system provides the same function. After development, manual processing required an intermediate or acid-stop bath of 30 seconds to neutralize the carried over developer. There is no intermediate bath in automatic processing.

Data Sheet & Comparison of Manual and Automatic Processing

Step 1	*Development*		
Name	**Manual Developer**	**Automatic Developer**	**Function**
Solvent	**Water**	**Water**	**universal solution to dissolve chemicals**
Accelerator or Activator	**Sodium Carbonate or Hydroxide**	**Sodium Carbonate or Hydroxide**	**softens and sweels the emulsion; provides alkalinity to the solution**
Reducing Agent	**Elon/Metol**	**Phenidone**	**fast acting, produces shades of gray**
Reducing Agent	**Hydroquinone**	**Hydroquinone**	**slow acting, builds density & contrast**
Restrainer	**Potassium Bromide**	**Potassium Bromide**	**prevents reducing agents from acting upon unexposed silver halide crystals**
Preservative	**Sodium Sulfite**	**Sodium Sulfite or Cycon**	**regulates oxidation to prolong the life of the developer**
Hardener	**none**	**Glutaraldehyde**	**hardens the film emulsion to accommodate roller transport**
Processing time	**5 minutes**	**22 seconds**	
Processing temp.	**68 degrees F**	**86-96 degrees F.**	
Agitation	**Manual**	**Roller transport**	
			A starter or additive of acetic acid or potassium bromide may be used to retard the high development activity of new developer. It is only added when all the developer is changed to "season" it.
Step 2	***Intermediate/Acid Stop Bath = 30 seconds in Manual***	***None in Automatic Processing***	**stops development and neutralizes residual chemicals from the developing solution**
Step 3	*Fixing*		
Name	**Manual Fixer**	**Automatic Fixer**	**Function**
Clearing Agent	**Sodium or Ammonium Thiosulfate/Hypo**	**Sodium or Ammonium Thiosulfate/Hypo**	**removes unexposed silver halide crystals from the emulsion**
Activator	**Acetic or Sulfuric Acid**	**Acetic or Sulphuric Acid**	**stops and neutralizes residual developer**

Hardener	**Potassium or Chrome Alum**	**Aluminum Chloride or Potassium Alum**	**shrinks and hardens the emulsion**
Preservative	**Sodium Sulfite**	**Sodium Sulfite**	**promotes archival quality of permanent image**
Fixing Time	**2 x Clearing time (usually 15-20 minutes)**	**22 seconds**	
Agitation	**Manual**	**Roller Transport**	
Step 4	***Final Wash***		
	20 minutes for screen film; 40 minutes for nonscreen film	**20 seconds with circulating water & roller transport**	
Step 5	***Final Drying***		
	30 minutes, but can be improved using a neutralizer & a wetting agent	**26 seconds at 120-150 degrees F. & roller transport**	**neutralizer eliminates carried over fixer and the wetting agent reduces surface tension so water "beads" up and runs off film surface**
Total Time	***1 hour+***	***90 seconds***	

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P.O. Box 2931 Toledo, Ohio 43606
Phone: 419-471-1973
Website: www.xrayhomestudies.com

Comparison of Manual & Automatic Processing

Manual - Advantages	Manual - Disadvantages
manipulation of image quality by using sight development	total processing time of 40-60 minutes
compensation for incorrect or questionable exposure factors	health risk from handling biohazardous materials
minimal supplies	slow production
no mechanical maintainence	quality varied based on number of individuals processing film

Automatic - Advantages	Automatic - Disadvantages
total processing time reduced to 90 seconds	no manipulation of image quality based on individual discretion
optional processing times available for dedicated imaging	inability to compensate for questionable exposure factors
improvements in quality control due to better temperature & replenishment systems & improved chemistry	regular maintainence and service needed with replacement parts, mechanical failures & q.c. monitoring
work capacity was increased	work flow ceases if only 1 processor is available for use
reduction in artifact production	equipment sabotage by disgruntled employees
minimal biohardous material contact	expensive original purchase
multiple processors would minimize delays or keep production operating	upgrades or total replacement as needs & technology improves

FIXING PROCESS

There are three primary functions for fixation. It is necessary to "clear" away the unexposed silver halide crystals, re-harden the film gelatin that was softened in the developer and to preserve a final archival image.[1(p194)] The chemical names and functions are listed on Step 3 of our chart. In manual processing, the fixing time was twice the clearing time. The clearing time meant the amount of time required to remove the unexposed silver bromide crystals. The film in fixation had a milky white appearance to it. Once this milky, cloudy appearance dissipated, the film was left in the fixer for the same amount of time again to harden it. This process usually took 15-20 minutes with screen film. The film had to be agitated by hand. In automatic processing, fixing time is approximately 22 seconds and agitation is accomplished by the roller transport system.

FINAL WASH

Once the films are fixed, it was important to put the film in a final wash tank so that the residual chemicals could be removed completely.[1(p195)] The final wash was ideally circulating fresh water. Screen film was placed in the final wash for approximately 20 minutes. Non-screen film was in the final wash for 40 minutes because it had a thicker emulsion and required a longer wash period. In automatic processing, the film is in the final wash tank for 20 seconds and the rollers move it through to the final drying stage.

FINAL DRYING

In manual processing techniques, it took approximately 30 minutes for the film to dry completely.[1(p194)] The time could be reduced if a neutralizer and wetting agent was utilized. The neutralizer minimized the possibilities of any residual chemicals on the film and the wetting agent reduced the surface tension of water so that the film could dry more quickly. Drying cabinets blowing hot air (about 100^{o}F) were used to reduce time and load multiple films. In automatic processing, the final drying time is approximately 26 seconds with the temperature at 120 to 150 degrees Fahrenheit. Roller transport is utilized to provide an even distribution of heat on the film surfaces as it is transported to the receiving bin.

In conclusion, the amount of time in processing a radiographic film by manual methods was approximately one hour while the current automatic processing time is 90 seconds. There are obviously advantages and disadvantages to both systems. The advantages of manual processing included the ability to use sight development. Sight development provided an opportunity for the radiographer to manipulate the film density and contrast to the desired level if errors were made in exposure calculations. One of the primary advantages of automatic processing is the shorter processing time in addition to the production and maintenance of consistent film results rather than utilizing individual radiographer's judgement.

RAPID AND EXTENDED PROCESSING

In addition to manual and automatic processing, we have rapid processing available on the market. Konica developed a 45-second processing system with Konica film in the late 1980's. Extended automatic processing of 3 1/2-7 minutes may be utilized in specific examinations that require a longer scale of contrast or a scale of the contrast that is critical such as mammography.

DAYLIGHT PROCESSING

The last system of film processing is daylight in which magazines are loaded with boxes of film. Multiple magazines could be used for multiple sized film. The magazines are lightproof and are inserted into the appropriate device such as a radiographic table or a dedicated chest unit. The film is advanced to the screen-grid location, exposed and then transported automatically to the processor that is either attached to the machine directly or by a short conveyor system to a processor.[1(p203)] Some processors may be shared.

XERORADIOGRAPHY

Xeroradiography is a specialized radiographic imaging/processing system that utilizes a charged aluminum plate that was coated with a selenium powder instead of conventional radiographic film. The selenium powder was distributed over an electrically conducive plate and then exposed to radiation. The radiation discharged the areas in proportion to the radiation received and created the "latent" image. The exposed cassette had to be inserted into a processing unit. The permanent image was produced by the selenium powder being electrostatically transferred to paper. The images were converted to a blue powder on a white paper base. Xeroradiography had major applications in mammography, foreign body localization, and bone detail studies. One of the problems and considerations in using Xeroradiographic technique was the high exposure in comparison to improving radiographic film and screen combinations.

PACS

There are commercial vendors available who have provided digitizing systems. The radiographic images are displayed on a computer console and can be manipulated by physicians situated at workstations. Some systems have become elaborate with interfacing to multiple devices and workstations. PACS represents Picture Archiving and Communication Systems.[1(p387)] The future of radiographic imaging, in addition to the current digital systems such as CT, MRI, ultrasound, etc., will universally be linked to a computerized electronic system for interfacing with multiple workstations in multiple facilities in multiple geographic locations.

SILVER RECLAIMING/RECYCLYING METHODS

There have been three methods developed to recover silver from the fixing solutions.

1. Electrolytic
2. Chemical precipitation
3. Metallic replacement

In the electrolytic method, the fixing solution is deposited in a canister that possesses and anode (+ charged) and cathode (- charged) section to the fixing solution. The unexposed silver halide crystals are ionized. The + silver atoms will be attracted to the cathode (-) and deposited out in an layering on a disc-like structure. The silver recovery unit has a motor on top to alter the amperage and voltage to maximize silver deposition and recovery. The electrolytic method is the most commonly utilized and efficient system available today.

Historically, chemical precipitation involved emptying the fixing solution in a large tank with the unexposed silver halide depositing out in the bottom of the chemical tank. In the metallic replacement method, the unexposed silver halide plated out on wire that was similar to steel wool.

ARTIFACTS

Artifacts come in various sizes, shapes, appearances, and densities. An artifact is considered any unwanted optical density that appears on the film and provides no diagnostic value.[1(p441)] Most of the artifacts that result on finished radiographs are produced at the time of exposure, during processing, or by handling situations before or after processing. Artifacts may be serious enough to interfere with the diagnostic information on the image and necessitate repeat exposures to the patient.

EXPOSURE ARTIFACTS

Most radiographers may not realize that patient motion may be considered an artifact. It is important to watch the patient during their respiratory activities when exposures are being made and to provide appropriate instructions for patient compliance.[1(p441)] Positioning errors may be considered exposure artifacts. Radiographers should make every attempt to be careful and conscientious during positioning of all patients so that additional exposures are not required due to personal carelessness or neglect. If the department utilizes a variety of film-screen combinations, radiographers must be conscientious in selecting the appropriate film-screen combination for the desired examinations. Obviously, if the wrong cassette combination is used, the resultant images may be either over- or under-exposed. In either situation, the patient may be subjected to an additional exposure due to poor judgment on the part of the radiographer performing the examination. Occasionally an inadvertent double exposure may occur when radiographers do not load and unload cassettes appropriately or get confused when performing examinations that require multiple cassettes. The selection of the wrong grid or improper utilization of a stationery grid, particularly during portable radiography, may be considered an artifact.

PROCESSING ARTIFACTS

There are multiple artifacts that can be produced during processing and after processing. If the roller transport system is not appropriately cleaned, sludge and chemical precipitation may deposit on the rollers and cause artifacts on the softened emulsion.[1(p443)] If the chemicals become exhausted, chemical fog may be added to the resultant image. The roller transport system and guide shoes can leave marks on the film and scratches. A scratch that is easily identifiable is called a Pi line. A Pi line is produced from a roller in the deep section that occurs at a periodic 3.14" separation. This artifact can be easily remedied by cleaning and realigning the roller tension. Chemicals can create stains and uneven development if they are not distributed evenly over the film surface during processing or washed completely from the film before final drying.

STORAGE AND HANDLING ARTIFACTS

Film is a sensitive product and must be maintained under certain conditions. Light and radiation fog can be produced on film that is stored inappropriately or handled under inappropriate lighting situations.[1(p443)] Crescent-shaped kink marks can be evidenced on the film by rough handling in the form of bending or by fingernail marks.[1(p445)] Static can be generated by darkroom conditions that are too dry. Some of the static configurations that we produce by the spark of light are described as Christmas tree-like or branch static. Pressure marks of fog can be produced by having boxes of film stored horizontally rather than vertically. The pressure and weight of the boxed above will create the risk of fog on the lower level boxed. As we mentioned earlier, film has an expiration date. It is to our advantage to utilize film before it expires so that unwanted densities will not be obvious.

INTENSIFYING SCREENS

TYPES OF LIGHT EMISSION

There are three principle types of light emission. Luminescence simply means an emission of light not directly attributable to the heat that produces incandescence.[1(p207)] The second type is fluorescence that means light will be emitted when a particular energy has been applied to it. The emission of light will cease once the energizing force has been removed. We use fluorescence in our intensifying screens. The crystals in the screen will continue to emit light while the x-ray photons are interacting with them. When the x-ray ceases, the light from the crystals ceases as well. The last type of emission is called phosphorescence. It has earlier synonyms of screen lag or "afterglow". In phosphorescence, the light-emitting source, which in most instances are crystals, continues to emit light after the energizing source has been removed. In radiography, we see phosphorescence in some of our earlier fluoroscopic screens where a residual image may exist after the machine is shut off. Most commonly in our every day life, we see it on our television screens. When we shut the television off, the image gradually disappears. Phosphorescence is not the type of light emission desired inside our intensifying screens. The screens would continue to give off light after the radiation ceases and the film would continue to be exposed unnecessarily. The processed films would have additional density that is not needed and would jeopardize the diagnostic quality of the image.

CONSTRUCTION OF INTENSIFYING SCREENS

Intensifying screens have four layers. There is a protective coating that prevents scratches or other injuries to the active layer of the screen construction. [1(p205)] The second layer is the most important. It is called the phosphor or active layer because it contains the crystals that will be fluorescing during radiation activation.

The crystals utilized in intensifying screens must possess certain properties to qualify in that function. The screen phosphor should have high atomic numbers so that the x-ray absorption is high.[1(p205)] The ability of the crystal to convert x-rays to light should be very high in producing the resultant image. The crystal layer should not provide any "afterglow" or phosphorescence because the film density will be increased. The crystals should not be affected by heat, humidity or other environmental agents it may be subjected to in clinical practice. The crystals should not deteriorate significantly with age.

The crystals in the active layer must be adhered to a reflective layer that in most instances is white so that light reflection can be optimized.[1(p206)] These three layers are then adhered to a screen base. The screen base should be sturdy, moisture resistant, and not contain impurities that would interfere with the image quality on the film. The screen base should be resistant to discoloring with age and not experience any significant radiation damage with years of use.

TYPES OF CRYSTALS

One of our early investigators utilized a crystal type that remains in clinical practice today. Thomas Edison was very influential in discovering and implementing the use of calcium tungstate crystals that give off a blue light. Our conventional fluoroscopic screens were designed with zinc cadmium sulfide crystals that give off a yellow-green light. In the 1970's Rare Earth crystals were designed and identified with higher conversion efficiency. This higher conversion efficiency allowed us to reduce patient exposure dosages as much as 50-75%. Some of the more popular Rare Earth crystals are Lanthanum Oxybromide which is a blue light emitter, Lanthanum Oxysulfide which emits green light, Gadolinium Oxysulfide emits green, and a series of barium compounds which emit ultraviolet light.[1(p208)] It is important for us to utilize screens that are matched to the spectral sensitivity of the film. Mismatching screens and films will result in images that are under-exposed and necessitate repeats.

CHARACTERISTICS OF SCREEN CONSTRUCTION

There are several factors that manufacturers of intensifying screens must consider when designing the screen. The individual with the responsibilities of selecting screens in the department must be knowledgeable so that the best combination can be achieved with the priority of reducing patient dose without compromising diagnostic information.

One screen characteristic includes the selection of the type of crystal. We know that Rare Earth crystals are much more efficient and thereby reduce patient exposure. The size of the crystal must be considered for the resultant detail on the image.[1(pp210-211)] Smaller crystals provide better detail when compared to a larger size crystal. Thickness of the crystal layer affects detail. Thinner layers of crystals provide better detail than thicker layers. A reflective backing that is white optimizes the amount and degree of light reaching the film. Screen conversion efficiency is higher with Rare Earth crystals when compared to conventional crystals.

Quantum mottle has to be considered in determining the ability of the crystals to react and respond to the random nature of the x-ray photons or light photons within the cassette structure.[1(p210)] The last factor to consider is the intensification factor. It is a comparison of the exposure with and without screens. It is a well-established fact that the light from the screens produce 95-98% of the energy needed to produce the resultant image. Patient dose will always be reduced using screens when compared to nonscreen exposures.

SCREEN SPEEDS

Based on the internal construction of the screen such as size, type, and thickness of crystals, a screen speed can be calculated that is usually referred to as a number.[1(p208)] Ultradetail/slow screens have a speed less than 100. Par or medium average screen speeds are the standard of comparison at 100, and fast/high-speed screens have speeds greater than 100. Ultradetail/slow screens have smaller crystals and provide good detail. Par screens have average crystal size with average detail. Fast screens have larger crystals and less detail. However, ultradetail/slow screens require a greater dose than par or fast. Rare Earth screens can provide speeds up to 1000. It is also important to realize that screens can be unmatched in a cassette. For example, a slow screen can be attached to the front of the cassette to optimize detail and a faster screen can be attached to the back of the cassette to salvage the light and radiation in the screen in an effort to reduce patient dose.

Let's calculate a film screen compensation example. A PA hand exposure required 5 mAs and 60 kVp with a par film/screen combination. If an ultradetail/slow film/screen combination is selected, the exposure would have to be increased two or three times to compensate for the smaller crystal size and thinner layer. The resultant exposure would then be 10-15 mAs at the same kVp. If a fast/high-speed film/screen combination were selected, the original exposure of 5 mAs at 60 kVp with par would have to be reduced by a factor of two or three. Therefore, the resultant mAs would be 1.4-2.5 mAs at the same kVp with the fast film/screen combination choice.

PATIENT EXPOSURE AND DETAIL

It may become confusing when comparing patient exposures to detail. The greatest dose to patients will result when using U.D./slow film/screen combinations in comparison to par or fast/high-speed systems. U.D. and slow film/screen combinations are recommended for use with small body parts when detail needs to be maximized. Examples of appropriate use of U.D./slow film/screen combinations include small extremities, foreign body localization, mammography, etc.

The least dose radiation to the patient occurs when faster film/screen combinations are used when compared to U.D./Slow or par. Fast film/screen combinations are recommended for larger body parts in which detail may not be as critical. Examinations include the abdomen, GI procedures, or examinations requiring multiple images.

CARE OF INTENSIFYING SCREENS

It is important for radiographers to utilize their equipment correctly and in a protective manner. Intensifying screens need to be cleaned appropriately following the manufacturer's recommendations for the cleaning agent to be utilized.[1(pp217-218)] Cassettes should not be left open when screen surfaces can be exposed to the risk of scratches or other particles such as dust. Screens need to be air dried, but not left open for prolonged periods of time. Screens should be cleaned on a regular schedule. It is also important for the cassette surfaces to be cleaned on a regular basis. A mild soap and water combination can be used without creating risk to the cassette construction.

FILM/SCREEN REALITIES

Even though radiographers may be knowledgeable about film/screen combinations, other personnel usually select the combinations to be used for various radiographic procedures. Physicists, radiologist preference, vendor contracts, etc. influence the decision on the manufacturer's film/screen products and cassettes utilized in clinical practice. Radiographers are obligated to use the particular combinations appropriately. Most facilities will want to minimize the film and screen types in their inventories so that confusion can be eliminated.

SAFE LIGHTS

When handling exposed film in the darkroom, radiographers should be cognizant of the fact that exposed film is approximately 2-8 times more sensitive to safe light illumination than unexposed film. Based on this fact, it is important to expedite the film from the cassette to the feed tray of the automatic processor without delay or prolonged exposure to safe lights. The safe light should be designed to provide enough visibility in the darkroom for personnel to accomplish all related duties in connection with the handling and processing of the x-ray film and cassette loading. The light emitted by the safe light should have the spectral qualities and intensity that does not fog the film handled under it for a reasonable period of time.

SAFELIGHT TESTING AND REQUIREMENTS

Because radiographic film is utilized in the darkroom before and after exposure, it is important to maintain appropriate safelight conditions for the film. The safelight should have an appropriate color and density of filter that will not provide unnecessary fog to the film.[1(p215)] For example, films that are blue-sensitive should have a safelight filter in the amber filter color range, while green-sensitive films may require a dark red filter. The safelight in most cases should not be located closer than 4-5 feet from the work surface. With conventional blue sensitive film, the Wratten Series 6B safe light was recommended with a 15-watt tungsten light source. This particular filter allowed light emission in the yellow and yellow-red portion of the spectrum which thereby minimized any film fog based on spectral sensitivity. The density and type of filter material used in the safe light with Rare Earth films should be correlated by the film manufacturer so that the appropriate filter is matched to the film. A red filter, Kodak GBX filter, is suitable for both green and blue sensitive films since its light wave energy is at the opposite end of the color spectrum. Rare Earth films require shorter wavelengths with filters of dark red. Sodium vapor safe lights emit a yellow-orange light and are sometimes installed to provide indirect illumination of the work area. Once the appropriate safelight has been selected and mounted in the darkroom, it is necessary to conduct a test. In performing the safelight test, it is necessary to expose an 8 x 10 sheet of film with a minimal level of radiation. Pre-exposed film is much more sensitive than film that has no exposure. The pre-exposed film is then unloaded from the cassette and placed on the work counter. An opaque material such as a sheet of cardboard is placed over the film. One inch of film should be uncovered for every one minute of safelight exposure. Once the entire sheet of film has been uncovered, it should be processed. The entire film should be evaluated for obvious added densities. For example, let's say the fourth-inch mark has a band of density. This notifies darkroom personnel that the film should not be exposed to safelight conditions longer than three minutes because fog will occur to detract from image quality.

PROCESSING TANK CALCULATIONS

In the days of manual processing, it was important for radiographers to calculate the volume of chemistry to be prepared for the stainless steel processing tanks. The darkroom had a developing tank, fixing tank, intermediate rinse tank, and washing tank. The fixing tank in most instances was twice as large as the developing tank since films had to stay in the fixing solution for a longer period of time. Correspondingly, the final wash tank had greater dimensions than the fixing tank because films had to stay in the final wash for long periods of time. Tank capacity was calculated by:

<u>Volume in gallons = height - 1 inch x length in inches x breadth in inches</u>

The number '231' represents the number of cubic inches in a gallon. If the tank dimensions are calculated in metric, it is necessary to calculate the volume in liters.

$$\text{Volume in liters} = \frac{\text{height - 2.5 cm x the length in centimeters x breadth}}{1000}$$

The number '1000' is used to represent the number of cubic centimeters or milliliters in one liter. Notice in both of these formulas, one inch or 2.5 cm must be subtracted from the height of the processing tank so that solutions would not spill over the top when film and hangers were inserted into the solution. Just for practice, let's calculate the following tank capacity in both English and Metric formulas.

The developing tank is 20 inches in height, 18 inches length and 10 inches in breadth.

$$\text{Gallons} = \frac{19 \times 18 \times 10}{231} \qquad \text{Liters} = \frac{475 \times 45 \times 250}{1000}$$

By placing the numbers in their respective locations in the formula, you should have arrived at a 53.4 liters in the tank, or 14.8 gallons. Since most departments have converted to automatic processing, it is no longer necessary for radiographers to calculate these volumes.

DARKROOM CONSTRUCTION

It is important for the darkroom to be constructed in a strategically convenient location in relation to the radiographic rooms so that radiographers are not consuming nonproductive time by transporting cassettes to and from a remote darkroom. The darkroom should be painted with a chemically resistant paint of a dull nature. The floor should be covered with linoleum or a chemically resistant material. Counterspaces should be of appropriate height and width to accommodate cassette and film loading and unloading. The counter should be grounded so that static can be minimized as a possible artifact on resultant images. Pass boxes should be installed in a lightproof manner in the walls.

Three forms of lighting should be available. General overhead lighting for cleaning, safe lighting for film processing activities, and in some instances, a view box was installed in the darkroom when manually processing.

The size of the darkroom should accommodate adequate movement without jeopardizing physical injury. Ventilation should be appropriate to minimize occupational hazards for the radiographer from chemical fumes and to provide a comfortable work environment with appropriate temperature and humidity. Humidity control is also important in minimizing problems with film storage.

There are choices for the darkroom entrance. (1) the standard single door which has been light-proofed; (2) the rotating door that allows entrance into the darkroom without risk to fogging film to the exterior; and (3) the maze that consists of a long outer hallway painted in dull black with entrance into the darkroom. No door is required because it is assumed that the dull black painted walls will absorb the extraneous light before the radiographer and cassettes reach the internal aspects of the darkroom space. There is also a double interlocking door. The single door or the double interlocking door should be equipped with an electric lock so that the door cannot be accidentally opened when the film bin is open. This eliminates costly accidental exposure to film bins loaded with multiple boxes of film sizes. If an electric lock is installed, it must open automatically in the event of power failure, otherwise, an emergency entrance must be provided for the darkroom. All radiographers should develop the habit of checking all film bins and feed trays before opening the single-door entrance.

Double interlocking doors, revolving doors and mazes permit radiographers to enter and leave the darkroom without disrupting the work in process if the darkroom serves multiple radiographic installations.

This concludes Unit 7. Please proceed to the unit questions and complete the required personal data.

Addendum, 2010: Some practices have already converted from conventional film-screen technology to digital imaging equipment. Many practices will be converting from conventional film-screen technology to digital imaging technologies in the upcoming years. Please feel free to consider utilizing the following self-learning units to expand your knowledge base and technical skills with computed radiography or digital imaging equipment and PACS.	Number of A.S.R.T. Category A CE credits
Set 17: Unit 36: ***Radiographic Imaging & Exposure*** by Terri L. Fauber	11
Set 23: Unit 42: ***Fundamentals of Special Radiographic Procedures*** by Albert M. Snopek	22.5
Set: 45: Unit 45: ***Digital Radiography and PACS*** by Christi Carter & Beth Veale	9
Please check the S.T.A.R.S. web site www.xrayhomestudies.com for current expiration dates and availability of these and new offerings in the future for your educational needs.	

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P.O. Box 2931 Toledo, Ohio 43606
Phone: 419-471-1973
Website: www.xrayhomestudies.com

Generalized Listing of Processor Quality Control Considerations

1. Keep the processor & rollers clean internally & externally with a regular schedule of preventative maintainence and replacement;

2. Thoroughly clean the processor before putting in fresh clemicals on a regular replacement schedule based on film volume and manufacturer's recommendations;

3. Check the immersion time of the film in all the processing solution compartments;

4. Check and monitor the pressure and temperature of the water supply;

5. Check and monitor solution temperatures on a daily basis;

6. Check and monitor the mechanical condition of the processor parts i.e. pulleys, gears, rollers, filters, etc.;

7. Check and maintain established parameters of the sensitometry strips on a daily basis;

8. Analyze the sensitometry strips on a daily basis and make corrections as soon as possible if standards are not evident, in addition to, analyzing any artifacts or film quality impairment due to processor-related problems;

9. Check the electrical supply to the processor upon installation and operation;

10. Take care of chemical leaks and spills as quickly as possible;

11. Instruct other employees on the safe operation and protocols of processor utilization and maintainence established by your facility;

12. Keep the darkroom and accessory equipment clean and organized;

13. Provide appropriate physical conditions relative to ventilation, humidity and the reduction of possible artifact generation, in addition to, appropriate size and location of storage areas; and

14. Follow O.S.H.A. requirements when handling processing solutions since they are considered hazardous materials by wearing protective apparel, goggles, etc.

Some Important Terms and/or Concepts in Unit 7

An x-ray film that has an emulsion on both sides is called duplitized.

If we are using a single sided film with emulsion, it must be placed in proper correlation in a cassette with a single screen. The emulsion side must be closest to the screen surface.

There are multiple types of radiographic film on the market to meet specific needs.

Speed or sensitivity describes the ability of the film to respond to light or radiation.

Film categorized as slow-speed has small crystals in thin layers that responds slowly to radiation.

Film in the fast or high-speed category has larger crystals in thicker layers that responds quickly to radiation.

Film contrast is provided by the manufacturer and is inherent in the film emulsion.

Latitude provides the radiographer an opportunity to make an error in exposure factor calculations and still renders an acceptable image. Films that are very forgiving are referred to as possessing wide latitude. Films that are very critical with minimal exposure error are considered narrow.

Crossover occurs when light or radiation enters the cassette and activates the crystal in the front screen. These light and radiation photons pass through the film and create light by the back screen. This process creates light and radiation bouncing between screens and through film emulsions.

A film may have a dye added to the base to make it more appealing and provide some density at the toe portion of the sensitometric curve.

Radiographers should be careful not to bend, crease or rough-handle film when opening boxes, loading and unloading cassettes, and handling the film after processing.

Film should be stored at approximately 68 degrees F or 20 degrees C with a 40-60% humidity factor.

It is not recommended to use film after the expiration date because an age fog may be present as an unwanted density if used in performing examinations.

Radiographic film should not be stored near sources of x- or gamma rays or devices producing heat such as radiators, vents, steam pipes or near chemical mixing areas.

Film boxes should be stored in a vertical position to eliminate pressure fog.

Radiographers should make every effort to minimize any risk of physical damage or artifact production on film so that radiographic quality will not be jeopardized.

The pallets used for warehousing film should be elevated at least 2" from the floor to prevent any risk of water damage.
The invisible image that is created by the silver halide crystals during exposure to light and radiation is termed latent.

The image that is visibly produced after processing has occurred is described at the manifest image.

The primary purpose of film development is to convert the exposed silver halide crystals to metallic silver.

The purposes of fixing are to "clear" away the unexposed silver halide crystals, re-harden the film gelatin that was softened in the developer and to preserve a final archival image.

Xeroradiography is a specialized radiographic imaging/processing system that utilizes a charged aluminum plate that was coated with a selenium powder instead of conventional radiographic film.

PACS represents Picture Archiving and Communication Systems.

The electrolytic method is the most commonly utilized and convenient-silver recovery system available today.

An artifact is considered any unwanted optical density that appears on the film and provides no diagnostic value.

Patient motion may be considered an artifact.

Positioning errors may be considered exposure artifacts.

Radiographers must be conscientious in selecting the appropriate film-screen combinations for the desired examinations.

The selection of the wrong grid or improper utilization of a stationery grid, particularly during portable radiography, may be considered an artifact.

Sludge and chemical precipitation may deposit on the rollers and cause artifacts on the softened emulsion.

A scratch that is easily identifiable is called a Pi line and is produced from a roller in the deep section that occurs at a periodic 3.14" separation.

Light and radiation fog can be produced on film that is stored inappropriately or handled under inappropriate lighting situations.

Static can be generated by darkroom conditions that are too dry.

Fluorescence means light will be emitted when a particular energy has been applied to it. The emission of light will cease once the energizing force has been removed.

Phosphorescence means light will be emitted by the crystals and continues to emit light after the energizing source has been removed.

In the 1970's Rare Earth crystals were designed and identified with higher conversion efficiency. This higher conversion efficiency allowed us to reduce patient exposure dosages as much as 50-75%.

Ultradetail/slow screens have a speed less than 100. Par or medium average screen speeds are the standard of comparison at 100, and fast/high-speed screens have speeds greater than 100. Rare Earth screens can provide speeds up to 1000.

U.D. and slow film/screen combinations are recommended for use with small body parts when detail needs to be maximized.

The least dose radiation to the patient occurs when faster film/screen combinations are used.

Intensifying screens need to be cleaned appropriately following the manufacturer's recommendations for the cleaning agent to be utilized.

Exposed film is approximately 2-8 times more sensitive to safe light illumination than unexposed film.

The darkroom should be constructed in a strategically convenient location in relation to the radiographic rooms so that radiographers are not consuming nonproductive time by transporting cassettes to and from a remote darkroom.

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[1] Bushong, SC. *Radiologic Science for Technologists: Physics, Biology, and Protection.* 7th ed. St. Louis, MO: Mosby, Inc., 2001.

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Units 1 – 7

Radiologic Physics and Protection Series

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6.5 Category A ces

Prepared by: Carolyn J. Frigmanski, M.A., B.S.R.T. ®
Founder, **S.T.A.R.S.**

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Sincerely,

Carolyn J. Frigmanski, M.A., B.S.R.T. ® Founder, S.T.A.R.S.

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Unit 1
Title: Introduction to Radiation Physics

1. The mass of an object in a gravitational field is called
   a. density
   b. weight
   c. mass
   d. mass gravity

2. The types of energy we use to produce our x-ray image <u>before</u> development are:
   a. chemical and kinetic
   b. nuclear and potential
   c. electrical and electromagnetic
   d. kinetic and potential

3. The types of energy we use to produce our x-ray image <u>after</u> development are:
   a. electrical and chemical
   b. nuclear and potential
   c. chemical and thermal
   d. kinetic and potential

4. The scientist who provided the information for the graphic representation of our elements in an orderly format was
   a. Bohr
   b. Einstein
   c. Thomson
   d. Mendeleev

5. The miniature solar system concept of the atom was provided by
   a. Galileo
   b. Bohr
   c. Einstein
   d. Dalton

6. The smallest part of an element that has all the properties of the element is called a
   a. molecule
   b. substance
   c. ion
   d. atom

7. The term used to describe silver and bromide atoms that combine to form the crystals in our film emulsion is a(n)
   a. molecule
   b. element
   c. substance
   d. covalent bond

8. The positively charged particle found in the nucleus is called the
   a. ion
   b. proton
   c. neutron
   d. electron

9. The smallest negatively charged particle of an atom is the
   a. neutron
   b. ion
   c. electron
   d. proton

10. Isotopes differ from ions because the atom has either gained or lost an(a)
   a. proton
   b. electron
   c. beta particle
   d. neutron

11. The shortest electromagnetic wavelength known to man is
   a. x-ray
   b. cosmic
   c. ultraviolet
   d. visible light

12. The EMR term which indicates the speed of light is
    a. velocity
    b. frequency
    c. hertz
    d. wavelength

13. An alpha particle is a form of particulate radiation consisting of a(n)
    a. Hydrogen atom
    b. Carbon cation
    c. Oxygen molecule
    d. Helium nucleus

14. The unit of radiation that can be measured in the primary x-ray beam is the
    a. Curie or Becquerel
    b. Rem or Sievert
    c. Roentgen or Coulomb/Kilogram
    d. Rad or Gray

15. The unit of radiation provided on your personnel monitoring report is the
    a. RAD or Gray
    b. mSievert or mRem
    c. mCurie or Becquerel
    d. mRoentgen

16. Radium become less radioactive over time because of a law called
    a. law of conservation of energy
    b. radioactive decay
    c. Einstein's theory of relativity
    d. inverse square law

17. The radiation that exits after passing through the patient to reach the image receptor is called
    a. remnant
    b. primary
    c. scatter
    d. particulate

18. The interaction of matter and radiation that produces a recoil electron is called
    a. Compton effect
    b. coherent scattering
    c. pair production
    d. photoelectronic effect

19. The interaction that does not occur in diagnostic x-ray is
    a. photoelectric
    b. Compton
    c. pair production
    d. classical scattering

20. The interaction that satisfies the law of conservation of energy and matter is called
    a. pair production
    b. photoelectric
    c. Compton
    d. coherent scattering

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Unit 2
Title: Basic X-ray Circuitry

1. Materials that allow electrons to flow easily are called
   a. semi conductors
   b. insulators
   c. conductors
   d. semi insulators

2. The electrification process using the electrical field of a charged object to confer a charge on an uncharged object is
   a. traction
   b. induction
   c. contact
   d. friction

3. The law of electrostatics which is similar to one of the laws of magnetism is
   a. unlike charges attract, like charges repel
   b. force is inversely proportional to the product of the charges
   c. charges are located on the exterior
   d. unlike charges repel, like charges attract

4. Electromotive force is a synonym for
   a. amp
   b. watt
   c. ohm
   d. volt

5. The scientist who established the relationship of volts = amps x ohms is
   a. Georges Ohm
   b. Michael Foraday
   c. Albert Einstein
   d. Benjamin Franklin

6. The type of current in which electrons oscillate back and forth every 1/120 second is called
   a. direct
   b. rectified
   c. alternating
   d. direct pulsating

7. In the three-wire system, the wire that does not carry electricity is called
   a. hot
   b. ground
   c. cold
   d. warm

8. The type of circuit used in older style Christmas tree lights where one bulb went out, they all went out is
   a. parallel
   b. alternating
   c. direct
   d. series

9. When current is on, the electromagnet will
   a. possess a magnetic field
   b. not possess a magnetic field
   c. not operate at all
   d. attract all materials

10. Transformers use the form of induction called
    a. self
    b. back emf
    c. mutual
    d. magnetic

11. The device that consists of an armature with current flowing in it within a magnetic field is a(n)
    a. generator
    b. motor
    c. transformer
    d. electromagnetic

12. An electrical device that operates on self induction and allows us to preselect kVp is called a
    a. transformer
    b. solenoid
    c. electromagnet
    d. autotransformer

13. The most efficient and expensive transformer on the market today is the
    a. shell type
    b. closed core
    c. air core
    d. open core

14. The process of converting A.C. to direct pulsating current is called
    a. inversion
    b. transformation
    c. rectification
    d. induction

15. Tungsten is used in x-ray tubes because it has a
    a. low atomic number
    b. low melting point
    c. exceptional density
    d. high thermal conductivity property

16. The process of using heat to "boil off" electrons at the cathode is called
    a. rectification
    b. thermionic emission
    c. space charge
    d. mutual induction

17. The portion of the primary beam that originates from ionizing tungsten atoms at the anode is
    a. characteristic
    b. brems
    c. secondary
    d. remnant

18. Calculating heat units for a three phase 12 pulse unit requires mA X seconds X kVp and
    a. X 1.35
    b. X .5
    c. X 1.41
    d. X 2

19. The manufacturer's chart that provides details about the maximum technical factors that can be used for an exposure is
    a. technique
    b. tube rating
    c. anode cooling
    d. cathode heating

20. One of the responsibilities for radiographers is to prolong x-ray tube life by
    a. disregarding unusual sounds
    b. utilizing low exposures all the time
    c. maximizing rotor time
    d. following recommended warming procedures

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Unit #3
Title Factors Affecting the Radiographic Image — Density

1. Quality radiographs can be consistently produced with a thorough knowledge of
   a. manual processing of film
   b. the Joint Commission requirements
   c. budgetary considerations
   d. visibility & sharpness of detail

2. The sharpness of detail as recorded information is controlled predominately by
   a. exposure factors
   b. darkroom conditions
   c. geometric factors
   d. equipment operation

3. Radiographic images that possess low noise have
   a. maximum optical densities
   b. minimal unwanted optical densities
   c. less detail
   d. high grain

4. The prime factor of exposure which determines the <u>number</u> of x-rays produced is
   a. mA
   b. kVp
   c. time
   d. mA and kVp

5. The prime factor of exposure which determines the <u>penetration</u> of the beam is
   a. kVp
   b. mA
   c. time
   d. mA and kVp

6. The degree of blackening on the film is the result of a combination of prime factors such as
   a. mA
   b. time
   c. kVp
   d. mA, kVp and time

7. The law that allows radiographers to manipulate mA and time to achieve the same density is
   a. inverse square
   b. compensation
   c. reciprocity
   d. half life

8. The law that provides radiographers the greatest degree of radiation protection is
   a. reciprocity
   b. inverse square
   c. compensation
   d. half life

9. The law that allows radiographers to produce <u>equally</u> diagnostic images when distance is altered is
   a. compensation
   b. inverse square
   c. reciprocity
   d. half life

10. As kVp is increased, the degree of blackening on the resultant image
    a. decreases
    b. remains the same
    c. increases
    d. becomes inconsistent

11. Disease processes that require an <u>increase</u> in the prime factors of exposure are called
    a. destructive
    b. multiplying
    c. subtractive
    d. additive

12. The resultant density on a finished image will increase as
    a. time of exposure decrease
    b. processing temperature rises
    c. screen speed decreases
    d. kVp decreases

13. Beam restriction affects density because the amount of scatter radiation
    a. decreases as collimation decreases
    b. increases as collimation decreases
    c. remains unchanged
    d. increases with the collimator's dimensions

14. Unwanted and non-diagnostic density on a finished radiograph is considered
    a. reciprocity density
    b. positive density
    c. fog
    d. background

15. As added filtration increases in thickness, the resultant effect on density will
    a. increase
    b. decrease
    c. remain the same
    d. increases as the atomic number increases

16. The useful diagnostic range of densities on a finished radiograph is
    a. .25-2.0
    b. 0.5-3.0
    c. .25-4.0
    d. .1-2.5

17. The speed factor refers to the step on the sensitometric curve that has a numeric value of
    a. 2.0
    b. 0.5
    c. .1.5
    d. 1.0

18. When utilizing the anode heel effect properly, the thinnest anatomical portion of the body parts
    a. should be placed at the cathode end
    b. should be placed transversely to the tube
    c. should be placed at the anode end
    d. should be placed longitudinally to the tube

19. The compensatory filter designed specifically for chest radiography is the
    a. wedge
    b. trough
    c. boomerang
    d. added

20. Select the <u>new exposure</u> mAs to be used to produce an <u>equally diagnostic film</u> if 120 mAs was used at 36" an the new distance is 60".
    a. 333 mAs
    b. 475 mAs
    c. 90 mAs
    d. 200 mAs

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Unit 4
Title: Factors Affecting the Radiographic Image - Contrast

1. Long scale contrast describes a finished radiograph possessing
   a. black and white shades only
   b. many shades of gray
   c. no valuable diagnostic information
   d. fog

2. When a physician requests an image with high contrast, he usually means
   a. long scale
   b. medium scale
   c. short scale
   d. a image with lots of gray shades

3. Contrast on the finished radiograph that was produced by the patient's inherent size, shape, and tissue densities is called
   a. subject
   b. film
   c. subject and film
   d. long scale

4. The exposure factor which contributes the most to radiographic contrast is
   a. mAs
   b. mA
   c. time
   d. kVp

5. As patient thickness and tissue density increases, the scale of contrast
   a. increases
   b. decreases
   c. remains the same
   d. gets shorter

6. Subject contrast may be altered when
   a. pathological process exists
   b. processing changes
   c. film type changes
   d. technique changes

7. Contrast scales which are provided by the commercial manufacturer are referred to as
   a. subject
   b. short
   c. film
   d. long

8. Increasing development temperature provides resultant images with
   a. more contrast
   b. short scale contrast
   c. excellent contrast
   d. less contrast

9. "Hardness" of the beam refers to the function of the filter in removing
   a. short wavelengths
   b. long wavelengths
   c. average wavelengths
   d. remnant wavelengths

10. The glass window of the x-ray tube acts as a filter and is called
    a. inherent
    b. added
    c. total
    d. compensatory

11. Total filtration is a combination of
    a. added and compensatory
    b. inherent and compensatory
    c. inherent and added
    d. wedge and trough

12. Every body part has the recommended kVp to utilize and is referred to as
   a. maximum
   b. average
   c. acceptable
   d. optimum

13. If the mAs is going to be halved, 90 kVp would have to be changed to
   a. 87
   b. approximately 103
   c. 80
   d. 110

14. If the mAs is going to be decreased 50%, 74 kVp would have to be changed to
   a. 63
   b. 100
   c. 85
   d. 94

15. Thicker, denser body parts produce
   a. less scatter
   b. the same scatter
   c. optimum scatter
   d. greater scatter

16. Methods to control scatter include
   a. increasing collimation
   b. increasing time
   c. increasing kVp
   d. decreasing kVp

17. Most departments that employ many radiographers doing a variety of radiographic exams will purchase
   a. wide latitude film
   b. narrow latitude film
   c. non-screen film
   d. single emulsion film

18. The inherent film product characteristic affecting the resultant scale of contrast is called
   a. latitude
   b. sensitivity
   c. film response
   d. film fog

19. When increasing a grid ratio, the scale of contrast will
   a. demonstrate no change
   b. improve by reducing scatter
   c. deteriorate radiographic quality
   d. only be determined by the patient

20. The total filtration of aluminum equivalent for diagnostic imaging tubes is approximately
   a. 1.5 mm
   b. 2.0 mm
   c. 2.5 mm
   d. 3.0 mm

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Unit 5
Title: Factors Affecting the Radiographic Image —Detail and Distortion

1. The term umbra refers to the
   a. fuzzy border surrounding the image
   b. magnification factor
   c. image proper
   d. location of the central ray

2-7. Match the geometric factor with its corresponding effect on sharpness of detail (You may use these items more than once.)

___ closest object-image distance possible

___ largest focal spot size

___ longest source-image distance

___ fastest film-screen combination possible

___ patient capable of holding still

___ shortest exposure time possible

a. increasing sharpness

b. decreases sharpness

c. no change in detail

8. Using a tube tilt in error on a projection that does not usually require it will produce
   a. productive distortion
   b. no distortion
   c. identical distortion
   d. non-productive distortion

9-11. Calculate the magnification factor for these situations.

_____ magnification factor when image size is 2" and object size is 1.5".

_____ magnification factor when image size is 4" and object size is 3".

_____ magnification factor when image size is 3" and object size is 2".

12. —14. Calculate the image size for these situations.

_______ object size is 3"; the S.I.D. is 72"; the S.O.D. is 36".

_______ object size is 6"; the S.I.D. is 40"; the S.O.D. is 20".

_______ object size is 2"; the S.I.D. is 36"; the S.O.D. is 24".

15-17. Calculate the % of magnification for these situations

_____ % image width is 4"; object width is 2".

_____ % image width is 6"; object width is 4".

_____ % image width is 3"; object width is 1.5".

18. The test device which can be used to evaluate spatial resolution in screens is
   a. parallel line type
   b. densitometer
   c. wire mesh
   d. sensitometer

19. The "speckled" appearance created from the distribution of silver halide crystals in the film emulsion is called
   a. mottle
   b. graininess
   c. noise
   d. edge gradient

20. The random interaction of x-rays and intensifying screen crystals is called
   a. noise
   b. graininess
   c. quantum mottle
   d. quantum mechanics

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Unit 6
Title: Accessory Devices Used in Radiographic Techniques

1. Grids are recommended for use when
   a. scatter radiation is minimal
   b. clean up is not important
   c. body parts measure over 10 –12 cm.
   d. scatter radiation may become extreme

2. Grids will
   a. improve contrast
   b. reduce dose to patient
   c. be helpful for all examinations
   d. reduce contrast

3. The height of the lead strip to the distance between them is
   a. selectivity
   b. grid radius
   c. grid ratio
   d. contrast improvement factor

4. Contrast improvement factor compares radiographs with a grid to those
   a. of higher grid ratios
   b. without a grid
   c. using higher grid frequencies
   d. using lower grid ratios

5. A finished radiograph with density in the middle and no density on the periphery of each side indicates
   a. an upside down grid
   b. off-center grid
   c. grid not moving
   d. incorrect grid ratio

6. An 8:1 grid ratio is used with 100 mAs. The corrected mAs for a 16:1 grid ratio is
   a. 25 mAs
   b. remains the same
   c. 75 mAs
   d. 150 mAs

7. A non-grid technique is 60 mAs. A 12:1 grid is used with a corrected mAs of
   a. 90 mAs
   b. 60 mAs
   c. 300 mAs
   d. 200 mAs

8. A beam-restricting device which requires the use of micro-switches is
   a. aperture
   b. P.B.L. device
   c. manual collimator
   d. cone

9. The radiographic projection that could best utilize the anode heel effect to advantage is
   a. AP dorsal spine
   b. PA colon
   c. lateral skull
   d. PA hand

10. The beam-restricting device that operates similarly to the lens of a camera is
    a. cone
    b. collimator
    c. aperture
    d. P.B.L. device

11. One of the disadvantages in utilizing a cylinder cone is
    a. decreased patient dose
    b. increased patient dose
    c. less penetration
    d. more density

12. A metallic wedge that can be inserted into the x-ray tube housing to improve the quality of the finished radiograph is a
    a. total filter
    b. inherent filter
    c. triangle filter
    d. compensatory filter

13. To utilize the anode heel effect properly, the anatomical part should be placed on the table with the thicker portion aligned to the
    a. anode portion of the tube
    b. cathode portion of the tube
    c. transversely to the tube
    d. longitudinally to the tube

14. Collimating the x-ray beam closely to the anatomical part warrants a/an
    a. decrease in primary radiation
    b. increase in secondary radiation
    c. increase in primary radiation
    d. increase in remnant radiation

15. The major function of any filter is to
    a. harden the beam
    b. soften the beam
    c. allow all x-rays through
    d. decrease patient dose

16. Restricting the primary beam with any device will result in images with
    a. less detail
    b. more fog
    c. more density
    d. greater detail

17. The grid ratio recommended for diagnostic exams using 90 kVp or less is
    a. 16:1
    b. 8:1
    c. 6:1
    d. 12:1

18. Manufacturers of grids must specify the following detail on the grid itself.
    a. composition of materials
    b. per cent of lead content
    c. thickness of grid
    d. grid ratio

19. The old technique of inserting a black sheet of paper inside a cassette was to
    a. cut exposure dose
    b. increase the density on resultant image
    c. reduce the density on the resultant image
    d. reduce detail

20. When using grids, compensatory filters and beam restricting devices, patient dose will be
    a. increased
    b. decreased
    c. remain the same
    d. fluctuate

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Unit 7
Title: Radiographic Film, Darkroom Processing and Intensifying Screens

1. Historically, the first radiographic film base was
   a. glass
   b. plastic
   c. cellulose nitrate
   d. tinted

2. The most important layer of film construction that actually creates the latent image is
   a. supercoating
   b. adhesive layer
   c. emulsion
   d. base

3. The ability of the radiographic film to respond to light or radiation is called
   a. latitude
   b. sensitivity
   c. crossover
   d. contrast

4. — 10. Match the chemical with its function.

____ sodium sulfate	a. reducing agent in manual developer
____ glutaraldehyde	b. accelerator/activator in manual processing
____ phenidone	c. a preservative common in both fixer and developer
____ metal/elon	d. neutralizes the alkalinity of carried over developing solutions
____ ammonium thiosulfate	e. hardener found in automatic developer
____ sodium carbonate	f. reducing agent in automatic developer
____ acetic acid	g. cleaning agent found in the fixer

11. Radiographic film storage conditions include
   a. 80°F at 50% humidity
   b. 70°F at 30% humidity
   c. 50°F at 68% humidity
   d. 68°F with 40-60% humidity

12. An exposure of 10 mAs was used with Par film. The new mAs using fast film would be
   a. 5 mAs
   b. 20 mAs
   c. 30 mAs
   d. 2 mAs

13. 50 mAs was used with Par film. The new mAs using slow film would be
   a. 15 mAs
   b. 90 mAs
   c. 150 mAs
   d. 300 mAs

14. The term that describes the invisible changes occurring in the silver halide crystals <u>after</u> exposure to x-ray is
    a. manifest
    b. latent
    c. duplitized
    d. non-manifest

15. A processing artifact that occurs every 3.14" on the film surface is
    a. sludge marks
    b. guide shoe marks
    c. kink marks
    d. Pi lines

16. The type of light emission which occurs from the screens inside the cassette is
    a. fluorescence
    b. luminescence
    c. phosphorescence
    d. screen lag

17. The most important layer in screen construction which provides light photons is
    a. protective coating
    b. base
    c. phosphor layer
    d. reflective backing

18. The crystal used in the construction of rare earth screens is
    a. calcium tungstate
    b. lanthanum/gadolinium oxysulfide
    c. zinc cadmium sulfide
    d. calcium sulfide

19. Screens constructed with big crystals in thick active layers are considered
    a. par
    b. average
    c. slow
    d. fast

20. The greatest <u>reduction</u> in radiation dose to the patient will occur with screens made of
    a. large crystals in thick layers
    b. small crystals in thick layers
    c. small crystals in thin layers
    d. large crystals in thin layers

[] The ASRT Department of Education has approved the post-test as part of a group for 6.5 Category A Continuing Education credit(s). See order form for current expiration date.

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Answer Sheet for: Units 1-7 Radiation Protection & Physics Series

Please place your lettered selection for each question in the respective box and return *ONLY this post test sheet to* S.T.A.R.S. office P.O. Box 2931 Toledo, Ohio 43606

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Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7
1.	1.	1.	1.	1.	1.	1.
2.	2.	2.	2.	2.	2.	2.
3.	3.	3.	3.	3.	3.	3.
4.	4.	4.	4.	4.	4.	4.
5.	5.	5.	5.	5.	5.	5.
6.	6.	6.	6.	6.	6.	6.
7.	7.	7.	7.	7.	7.	7.
8.	8.	8.	8.	8.	8.	8.
9.	9.	9.	9.	9.	9.	9.
10.	10.	10.	10.	10.	10.	10.
11.	11.	11.	11.	11.	11.	11.
12.	12.	12.	12.	12.	12.	12.
13.	13.	13.	13.	13.	13.	13.
14.	14.	14.	14.	14.	14.	14.
15.	15.	15.	15.	15.	15.	15.
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18.	18.	18.	18.	18.	18.	18.
19.	19.	19.	19.	19.	19.	19.
20.	20.	20.	20.	20.	20.	20.