Imaging Equipment and Maintenance
Topic 1: Basic Concepts of Electricity

Electric Charges

- Electric charges can be **positive** or **negative**.
- Charged particles have **potential (stored) energy**, meaning they can do work when they move.
- The **smallest units of electric charge** are:
  - **Electron** – negative charge
  - **Proton** – positive charge
- The **fundamental SI unit of electric charge** is the **coulomb (C)**.

Electric Field

- An **electric field** is the **lines of force** that cause charged particles to move.
- It explains how one charge can affect another **without direct contact**.
- Electric fields guide the movement of electrons from one pole to another.

Electrostatics

- **Electrostatics** is the study of **stationary (non-moving) electric charges**.
- It focuses on how electric charges behave when they are at rest.

Electrostatic Laws

Electrostatics follows several basic laws that explain how charges interact.

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1. Law of Repulsion and Attraction

- Electric fields:
  - Radiate **outward from a positive charge**
  - Move **toward a negative charge**
- **Like charges repel** each other (positive–positive or negative–negative).
- **Unlike charges attract** each other (positive–negative).
- **Uncharged particles** do not produce an electric field.
- The attraction or repulsion between charges is caused by the **electric field** and is called **electrostatic force**.

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2. Inverse Square Law

- The force between two electric charges:
  - Is **directly proportional** to the product of their charge magnitudes.
  - Is **inversely proportional** to the **square of the distance** between them.
- This means:
  - Charges closer together have a stronger force.
  - Charges farther apart have a weaker force.

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3. Law of Distribution

- In a **solid conductor**, electric charges:
  - Spread out **uniformly on the surface**.
  - This happens because like charges repel each other.

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4. Law of Concentration

- Electric charges tend to concentrate:
  - **Most strongly at sharp or pointed areas** of a surface.
- In x-ray tubes:
  - Components are **rounded and highly polished** to prevent charge buildup at sharp points.

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5. Law of Movement

- **Only negative charges (electrons)** are free to move along solid conductors.
- **Positive charges** are tightly bound within the atomic nucleus and do not move.

Electricity (Energy Conversion)

- Electrical energy can be converted into other forms:
  - **Chemical → Electrical** (battery)
  - **Electrical → Mechanical** (motor)
  - **Electrical → Thermal** (electric barbecue)

Electrification

- **Electrification** is the **transfer or movement of electrons** from one object to another.
- It describes how electrons are:
  - Added to an object, or
  - Removed from an object
- Electrification occurs through **three methods**:
  - **Friction**
  - **Contact**
  - **Induction**

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1. Friction

- Happens when two objects are **rubbed together**.
- **Low humidity** (cold weather) makes electron transfer easier.
- Examples:
  - Rubbing hands together
  - Combing hair

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2. Contact

- Occurs when **two objects touch**, allowing electrons to move between them.
- Charges become balanced through **simple equalization**.

- Example:
    - Walking on a woolen carpet in low humidity and touching an object.

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3. Induction

- Occurs when **electric fields act on another object without direct contact**.
- This is the **most important method** because it is used in electronic devices.
- Used in:
    - Transformers
    - Electric motors
- Examples:
    - Induction motor
    - Lightning

Electrodynamics

- **Electrodynamics** is the study of **electric charges in motion**, which is electricity.
- It focuses on **electron movement**.
- Electron flow:
    - Is **facilitated** by materials that allow electrons to move easily.
    - Is **inhibited** by materials that resist electron flow.

Four States of Matter (Based on Electrical Behavior)

Materials are classified based on how they allow electrons to move.

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1. Conductors

- In conductors, **electrons move freely**.
- Examples include:
    - Most metals
    - Copper and silver (very good conductors)
    - Tap water containing impurities
- **Electric current flows easily** through conductors.

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2. Insulators

- In insulators, electrons are **held tightly** and are **not free to move**.
- Examples include:
    - Rubber
    - Wood
    - Glass
    - Many plastics
- **Electric current does not flow** through insulators.

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3. Semiconductors

- Semiconductors can act as:
    - Conductors, or
    - Insulators
- Their behavior depends on:
    - How they are made
    - Their surrounding conditions
- In x-ray circuits:
    - **Rectifiers** are made of semiconducting materials.
    - They allow electron flow in **one direction only**.
- Some semiconductors change behavior based on environmental conditions.

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4. Superconductors

- Superconductors are materials that:
    - Conduct electricity with **zero resistance**.
- They are used to produce:
    - **Magnetic fields** in magnetic resonance imaging (MRI) units.

Electric Current

- **Electric current** is the **movement of electrons** along a wire.
- Types of electric current:
    - **Direct Current (DC)**
    - **Alternating Current (AC)**
- Unit of electric current:
    - **Ampere (A)**
- Symbol:
    - **I**
- One ampere means:
    - **1 coulomb (C) of charge flows through a conductor each second**.
- Electrons at **high voltage** have:
    - High potential energy
    - High capacity to do work
- **High resistance** inhibits electron flow.

Direction of Flow

- **Conventional current flow**:
    - From **positive to negative** poles
- **Electron flow**:
    - From **negative to positive** poles

Direct Current (DC)

- Electrons flow in **one direction only**.
- All electrons move in the **same direction**.
- **Waveform**: straight line.
- **Application**: used in the **x-ray tube**.

Alternating Current (AC)

- Electrons flow **back and forth**, changing direction.
- **Waveform**: **sinusoidal**.
- **Application**: used in a **transformer**.

Potential Difference

- Also called:
    - **Electric potential**
    - **Voltage**
    - **Electromotive force (EMF)**
- It is the **force or strength** that causes electrons to move.

- It is the **maximum difference in electrical potential** between the positive and negative ends of an electron source.

Potential Difference / Voltage

- Unit: **volt (V)**.
- **Higher voltage** gives electrons **higher energy**.
- X-ray circuits use voltages up to **20,000 V**.
- **1 kilovolt (kV) = 1,000 volts**.

Voltage and Current Relationship

- Voltage acts like **electrical pressure** that pushes electrons.
- Increasing voltage increases **current flow**.
- This is similar to **water pressure**:
  - Higher pressure → more water flow
  - Higher voltage → more current flow
- Electrons move because of a **difference in pressure**, also called **potential difference (PD)**.

Imaging Equipment and Maintenance
Topic 2: Resistance, Circuits, and Power

Resistance / Resistor

- **Resistance** is the opposition to the flow of electrons.
- A **resistor** is a device that inhibits electron flow.
- Related terms:
  - **Admittance** – measure related to resistance in **AC**
  - **Conductance** – measure related to resistance in **DC**

Role of Resistance in X-ray Machines
Resistance is carefully controlled to ensure that:

- The **filament heats properly**
- The **tube current (mA)** is accurate
- The system remains **safe and stable**

Factors Affecting Resistance
Resistance depends on several physical factors:

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1. Ability to Conduct Electrons

- **Conductors**
  - Allow electrons to flow easily
  - Have **low resistance**
- **Insulators**
  - Do not allow free electron movement
  - Have **high resistance**

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2. Length of the Conductor

- Resistance is **directly proportional** to length.
- **Longer wire** → higher resistance
- **Shorter wire** → lower resistance

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3. Cross-sectional Diameter

- Resistance is **inversely proportional** to diameter.
- **Large diameter** → less resistance
- **Small diameter** → more resistance

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4. Temperature

- Resistance is **directly proportional** to temperature.
- **Higher temperature** → higher resistance
- **Lower temperature** → lower resistance

Electric Circuits

- An **electric circuit** is a complete pathway that allows electrons to:
  - Move from the source
  - Pass through electrical devices
  - Return to the source
- **Copper wire** is the most common pathway for electron movement.
- Two main types of circuits:
  - **Series circuit**
  - **Parallel circuit**

Ohm's Law

- Ohm's Law explains the relationship between:
  - Voltage (V)
  - Current (I)
  - Resistance (R)
- Core relationships:
  - Voltage depends on current and resistance
  - Current depends on voltage and resistance
  - Resistance depends on voltage and current

(Numerical problem-solving examples are intentionally excluded.)

Series Circuit

- In a **series circuit**, all electrical components are:
  - Connected **in a single line**
  - Located along the **same conductor**
- The circuit:
  - Supplies a **greater total potential difference**

    - **Requires all resistances to be operable**
    - Will stop working if **one component fails**

Rules of a Series Circuit

- **Total current** is the **same** through all components.
- **Total resistance** is the **sum** of all individual resistances.
- **Total voltage** is the **sum** of the voltages across each component.

Characteristics of Series Circuits

- Current does not change as it moves through the circuit.
- Voltage is **divided** among the resistive elements.
- Resistance increases as more components are added.

Parallel Circuit

- In a **parallel circuit**, components are:
    - Connected at their **ends**
    - Not arranged in a single line
- The circuit:
    - Offers **less total resistance**
    - Continues operating even if **one component is interrupted**
    - Operates with **greater total current**

Rules of a Parallel Circuit

- **Total voltage** is the **same** across each circuit element.
- **Total current** is the **sum** of the currents through each branch.
- **Total resistance** depends on the combined effect of all branches and is **lower than any individual resistance**.

Characteristics of Parallel Circuits

- Each branch receives the **same voltage**.
- Current is divided among different paths.
- Adding branches **decreases total resistance** and **increases total current**.

Devices That Prevent Short Circuits

Short circuits can cause overheating and damage, so protective devices are used.

Circuit Breaker

- Prevents short circuits.
- Designed to **break the circuit** before a dangerous temperature is reached.
- Can be **reset** after the problem is identified and corrected.

Fuse

- Prevents short circuits and protects circuit elements from **overload**.
- Works during a **power surge**.
- Constructed with a **metal tab** that melts when overheated.
- **Not reusable** and must be **replaced** after use.

Rheostat

- Also called a **potentiometer** or **choke coil**.
- A **variable resistor**.
- Used to **vary voltage or current**.
- **Main purpose**: to control current.
- **Location**: filament circuit.

Electric Power

- **Electric power** is measured in **watts (W)**.
- One watt equals:
    - **1 ampere × 1 volt**
- Power relationships include:
    - Power depends on current and voltage.
    - Power loss is related to current and resistance.
- X-ray imaging systems typically operate within:
    - **20–150 kilowatts (kW)**.