SAWA UNIVERSITY

اساسيات الفيزياء الشعاعية/ الكورس الاول

X-RAY PRODUCTION

Sawa University	جامعـــــــة ســـــــاوة الاهلية
College of health and medical techniques	كليـــــة التقنيـــات الصحيـة والطبيـة
Department of Radiology Tech.	قسم تقنيات الاشعة والسونار
Second Stage	المرحلـــــــــــة الثانية

الجانب النظري محاضرة رقم (4)

Lecture No. (4) Theoretical

تدريسي المادة : م.م. احمد عكاب شراد

(FUNDAMENTAL PROCESS OF X-RAY PRODUCTION)

Electrons are emitted by thermionic emission from the heated tungsten filament and accelerated across a high potential difference (kVp). When these electrons strike the tungsten target, they interact with its atoms through:

- Ionization or excitation (producing heat)
- Electron–electron and electron–nucleus interactions (producing X-rays)

These interactions depend on the energy of electrons, atomic number of the target, and tube voltage applied.

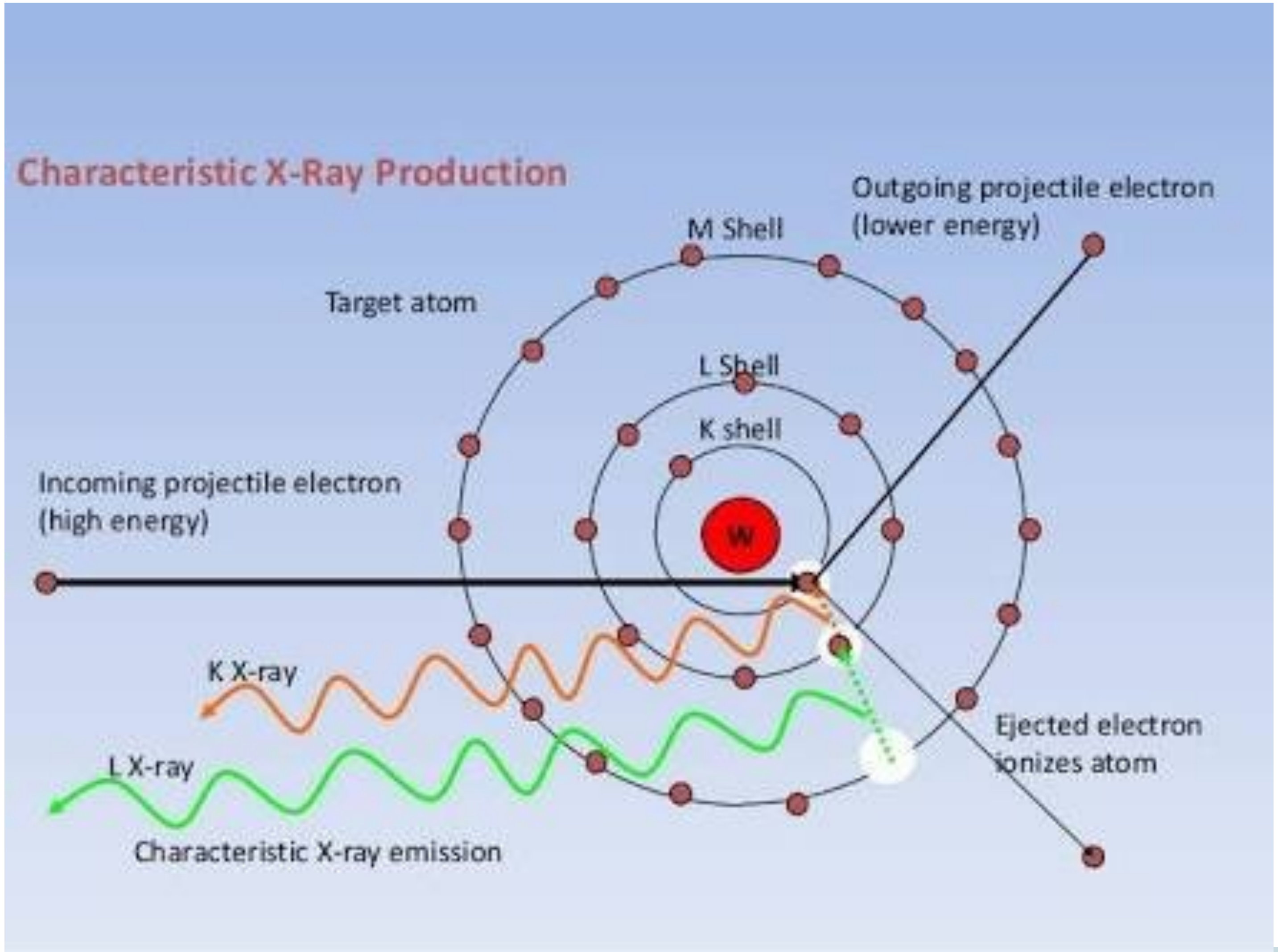
(CHARACTERISTIC RADIATION)

Characteristic radiation arises when a high-speed electron from the cathode knocks out an inner-shell electron (usually K or L shell) from a tungsten atom in the target. When an outer-shell electron drops down to fill the vacancy, a discrete amount of energy is released in the form of an X-ray photon. The photon energy equals the difference between the binding energies of the two shells:

$$E_{X-ray} = E_{outer} - E_{inner}$$

This process produces discrete (line) radiation with

(CHARACTERISTIC RADIATION)



(CHARACTERISTIC RADIATION)

For a tungsten target:

- K-shell binding energy = 69.5 keV.
- L-shell binding energy ≈ 12.1 keV

Thus, when an L electron fills a K vacancy:

$$E = 69.5 - 12.1 = 57.4\ keV$$

This produces a **Kα X-ray photon**. Similarly, an M → K transition produces **Kβ radiation (~67 keV).**

Characteristic X-rays appear only when the tube voltage exceeds the binding **energy threshold** of the target's inner shells.

(BREMSSTRAHLUNG RADIATION)

The term **Bremsstrahlung** (German for "braking radiation") refers to X-rays produced when high-speed electrons are **deflected or decelerated** by the **nuclear electric field** of tungsten atoms.

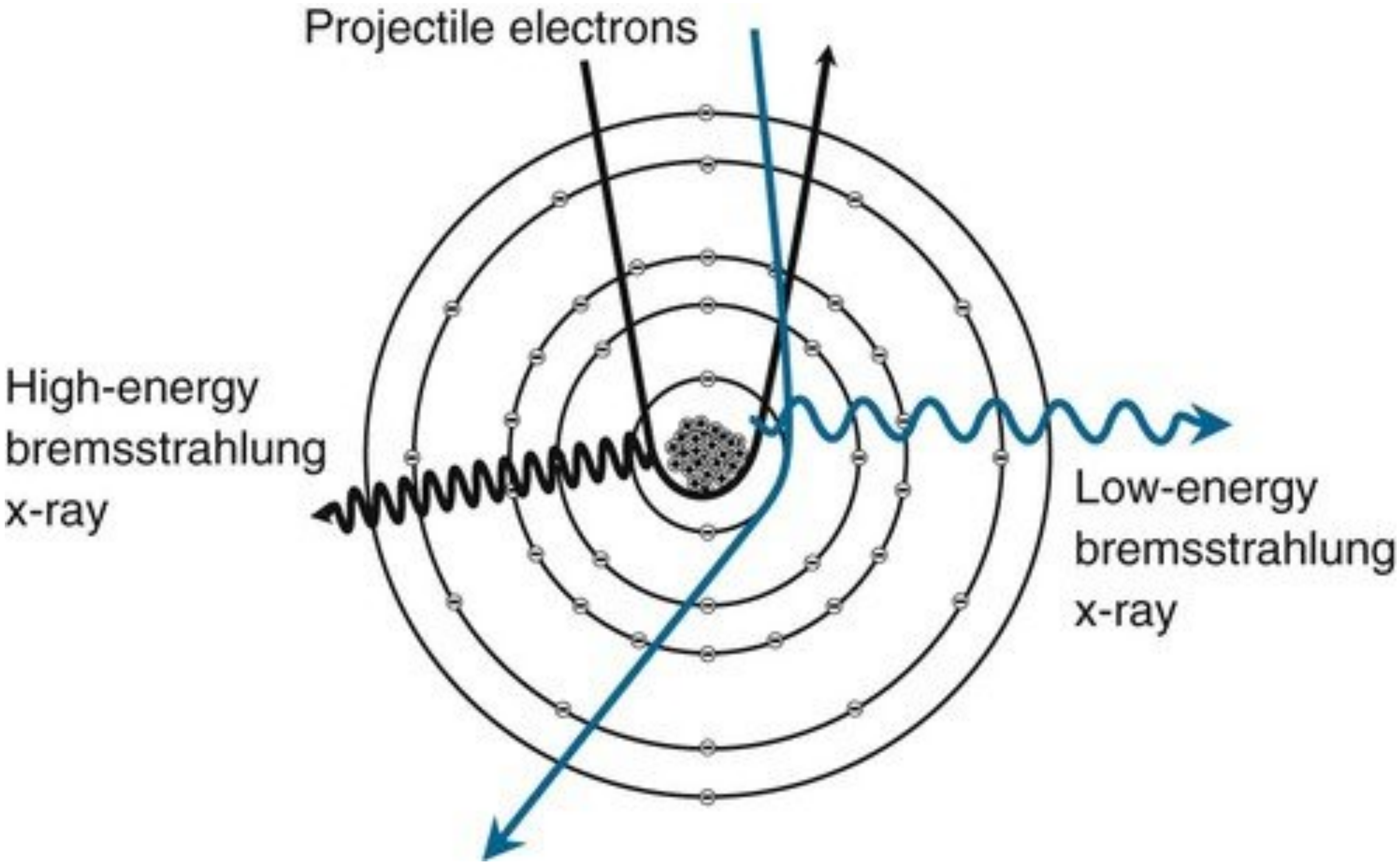
The closer the electron passes to the nucleus, the greater the deceleration and the **higher the photon energy** released.

This process results in **continuous radiation** with energies ranging from near zero up to the maximum energy (equal to tube voltage, kVp).

(BREMSSTRAHLUNG PROCESS)

When an incoming electron approaches the positively charged nucleus, it experiences a strong Coulombic attraction, changing its direction and speed. The energy lost during this deceleration is emitted as an X-ray photon. Because each interaction varies in intensity and deflection angle, Bremsstrahlung radiation forms a **continuous energy spectrum**, in contrast to the discrete lines of characteristic radiation.

(BREMSSTRAHLUNG RADIATION)



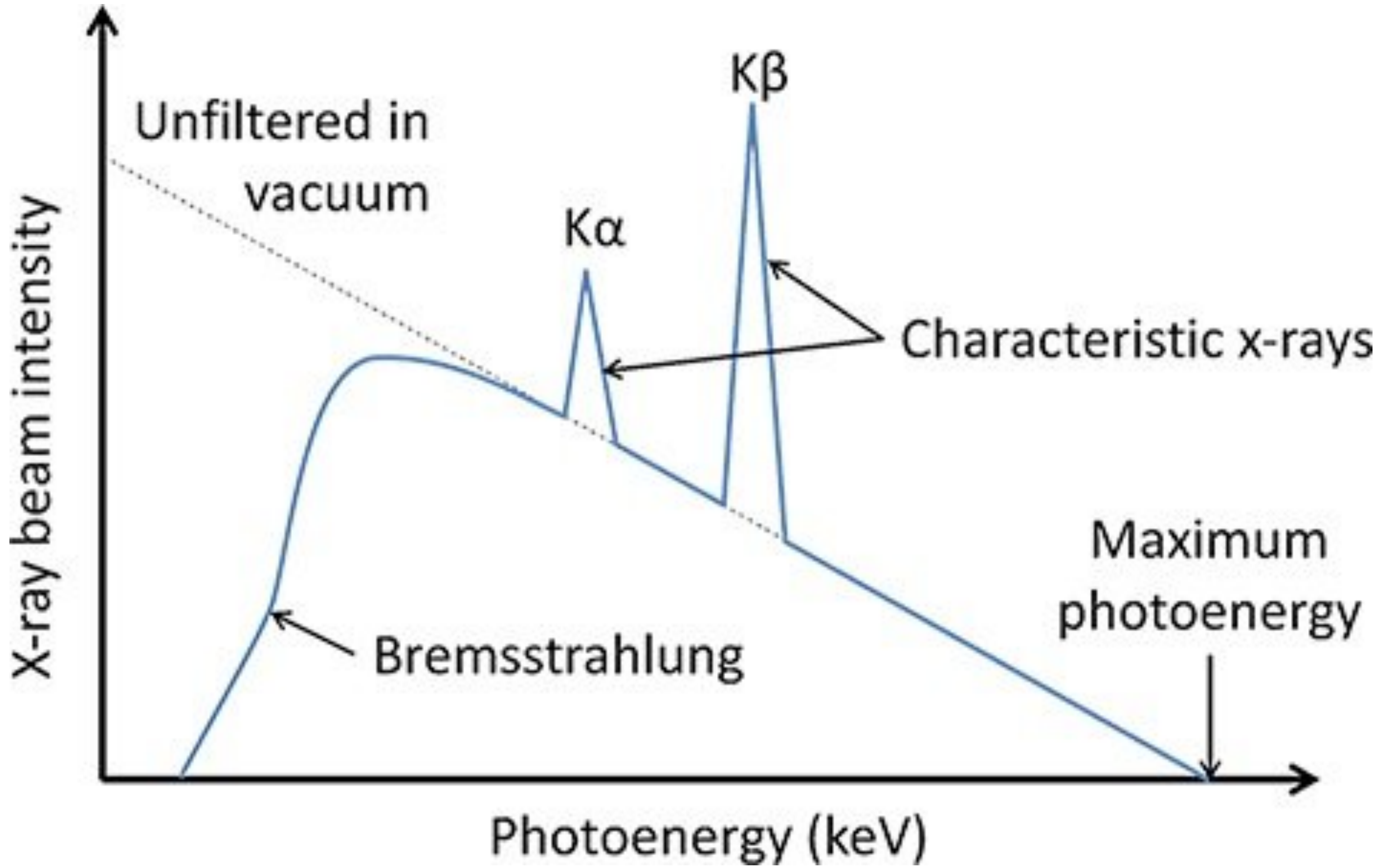
(EMISSION SPECTRUM)

The X-ray emission spectrum represents the distribution of X-ray photon energies produced in the tube.It consists of:

- **A continuous spectrum** from Bremsstrahlung radiation.
- **Characteristic peaks** superimposed on it, representing transitions within the tungsten atom.

The **maximum photon energy** corresponds to **the applied tube voltage (kVp),** while the number of photons depends on **tube current (mA)** and exposure time.

(EMISSION SPECTRUM)



(BREMSSTRAHLUNG — IMPORTANCE IN IMAGING AND DOSE)

Bremsstrahlung radiation forms the major component (about 80–90%) of diagnostic X-rays. It determines both **image formation** and **patient dose**:

- **Higher-energy Bremsstrahlung photons** improve penetration, reducing contrast but lowering skin dose.
- **Lower-energy photons** increase patient dose without improving image quality and are therefore filtered out.

Proper control of tube voltage and filtration ensures a balance between image quality and radiation protection.

(INFLUENCE OF ELECTRON ENERGY (KVP))

The **kinetic energy of electrons** (determined by tube voltage) directly affects the **maximum and average photon energy** of Bremsstrahlung radiation.

- Increasing kVp → increases maximum photon energy and intensity.
- Decreasing kVp → lowers both.

High kVp produces a **harder (more penetrating)** X-ray beam, which improves imaging of thick anatomical regions but reduces image contrast.

INFLUENCE OF TARGET MATERIAL

The atomic number (Z) of the target material significantly affects both the intensity and efficiency of X-ray production. Bremsstrahlung intensity is approximately proportional to Z^2. Thus, tungsten ($Z = 74$) is chosen for diagnostic tubes because it:

- Produces high-intensity X-rays.
- Has a high melting point (3,370°C),
- Generates characteristic lines in the diagnostic energy range (50–70 keV)

INFLUENCE OF FILTRATION

Filtration selectively removes low-energy photons that do not contribute to image formation but increase patient dose. Two types of filters are used:

- **Inherent filtration**: From glass envelope, oil, and window (~0.5–1 mm Al equivalent).
- **Added filtration**: Usually, aluminum or copper sheets are placed in the beam path (~1–3 mm Al).

Filtration "hardens" the beam by increasing its average photon energy, improving image consistency and patient safety.

SUMMARY OF FACTORS AFFECTING X-RAY SPECTRUM

1. Tube Voltage (kVp): Determines maximum photon energy and beam quality.
2. Tube Current (mA): Controls photon quantity.
3. Exposure Time: Affects total number of photons emitted.
4. Target Material: Alters both intensity and characteristic peaks.
5. Filtration: Removes soft radiation, increasing mean energy.
6. Anode Angle: Affects effective focal spot and output intensity.

SPECTRUM COMPARISON

If we compare two X-ray spectra:

- Increasing kVp shifts the spectrum rightward (higher energy) and upward (higher intensity).
- Increasing filtration shifts it rightward but downward (reduced intensity).
- Changing target material shifts characteristic peaks to new energy values corresponding to the element’s binding energies.

CLINICAL RELEVANCE

Understanding X-ray production is crucial for:

- Optimizing exposure parameters (kVp, mA, filtration) to achieve diagnostic image quality with minimal dose.
- Recognizing beam hardening effects in CT and conventional radiography.
- Selecting proper target materials for specialized imaging (e.g., molybdenum for mammography).

SUMMARY

- X-rays originate from interactions between high-speed electrons and the target.
- Two types of radiation: Characteristic (discrete) and Bremsstrahlung (continuous).
- The overall X-ray emission spectrum depends on tube voltage, target material, and filtration.
- Proper understanding of these principles ensures optimal imaging quality and safe radiographic practice.

QUIZ

1. WHICH OF THE FOLLOWING BEST DESCRIBES THE PURPOSE OF THE ROTATING ANODE IN X-RAY TUBES?

A. TO INCREASE THE PENETRATION POWER OF X-RAYS. B. TO DISTRIBUTE HEAT OVER A LARGER TARGET AREA.

C. TO REDUCE THE FOCAL SPOT SIZE. D. TO MINIMIZE THE HEEL EFFECT.

. Q2. EXPLAIN WHY MORE THAN 99% OF THE ELECTRON ENERGY STRIKING THE ANODE IS NOT CONVERTED INTO USEFUL X-RAYS.

.Q3. AN EXPOSURE IS MADE AT 80 KVP, 200 MA, AND 0.2 SECONDS USING A THREE-PHASE GENERATOR (CONSTANT = 1.35). CALCULATE THE HEAT UNITS (HU) PRODUCED.

Q4 DIFFERENTIATE BETWEEN THE ACTUAL FOCAL SPOT AND THE EFFECTIVE FOCAL SPOT IN THE LINE FOCUS PRINCIPLE.

.Q5. DISCUSS THE CLINICAL IMPORTANCE OF TUBE RATING CHARTS AND HOW RADIOGRAPHERS CAN USE THEM TO PREVENT TUBE DAMAGE DURING HIGH-LOAD PROCEDURES.

Any questions?

Thank You