Atomic and Molecular Physics

Presented by

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Second-year students

Lecture 6
X-Rays

6.1 Discovery of X-rays

In late 1895, a German physicist, W. C. Roentgen was working with a cathode ray tube in his laboratory. He was working with tubes similar to our fluorescent light bulbs. He evacuated the tube of all air, filled it with a special gas, and passed a high electric voltage through it. When he did this, the tube would produce a fluorescent glow. Roentgen shielded the tube with heavy black paper, and found that a green colored fluorescent light could be seen coming from a screen setting a few feet away from the tube. He realized that he had produced a previously unknown "invisible light," or ray, that was being emitted from the tube; a ray that was capable of passing through the heavy paper covering the tube. Through additional experiments, he also found that the new ray would pass through most substances casting shadows of solid objects on pieces of film. He named the new ray X-ray, because in mathematics "X" is used to indicated the unknown quantity.

In his discovery Roentgen found that the X-ray would pass through the tissue of humans leaving the bones and metals visible. One of Roentgen's first experiments late in 1895 was a film of his wife Bertha's hand with a ring on her finger. The news of Roentgen's discovery spread quickly throughout the world. Scientists everywhere could duplicate his experiment because the cathode tube was very well known during this period. In early 1896, X-rays were being utilized clinically in the United States for such things as bone fractures and gun shot wounds.

6.2 Production of X-rays

An X-ray tube is a vacuum tube designed to produce X-ray photons. The first X-ray tube was invented by Sir William Crookes. The Crookes tube is also called a discharge tube or cold cathode tube. A schematic x-ray tube is shown below.
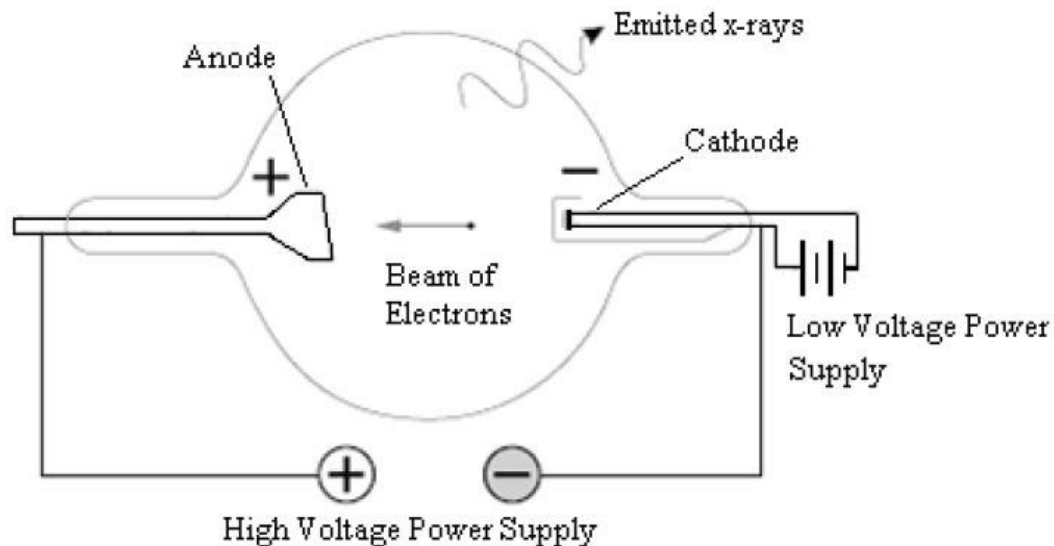

Fig.6.1: A Schematic Diagram of an X-Ray Tube

The glass tube is evacuated to a pressure of air, of about 100 pascals, recall that atmospheric pressure is 10^6 pascals. The anode is a thick metallic target; it is so made in order to quickly dissipate thermal energy that results from bombardment with the cathode rays. A high voltage, between 30 to 150 kV, is applied between the electrodes; this induces an ionization of the residual air, and thus a beam of electrons from the cathode to the anode ensues. When these electrons hit the target, they are slowed down, producing the X-rays. The X-ray photon-generating effect is generally called the Bremsstrahlung effect, a contraction of the German "brems" for braking, and "strahlung" for radiation.

The radiation energy from an X-ray tube consists of discrete energies constituting a line spectrum and a continuous spectrum providing the background to the line spectrum.

6.3 Properties of X-rays

- ➢ **X-rays travel in straight lines.**

- ➢ **X-rays cannot be deflected by electric field or magnetic field.**

- ➢ **X-rays have a high penetrating power.**

- ➢ **Photographic film is blackened by X-rays.**

- ➢ **Fluorescent materials glow when X-rays are directed at them.**

- ➢ **Photoelectric emission can be produced by X-rays.**

- ➢ **Ionization of a gas results when an X-ray beam is passed through it.**

6.4 X-Ray Diffraction

A plane of atoms in a crystal, also called a Bragg plane, reflects X-ray radiation in exactly the same manner that light is reflected from a plane mirror, as shown in Fig.6.4.
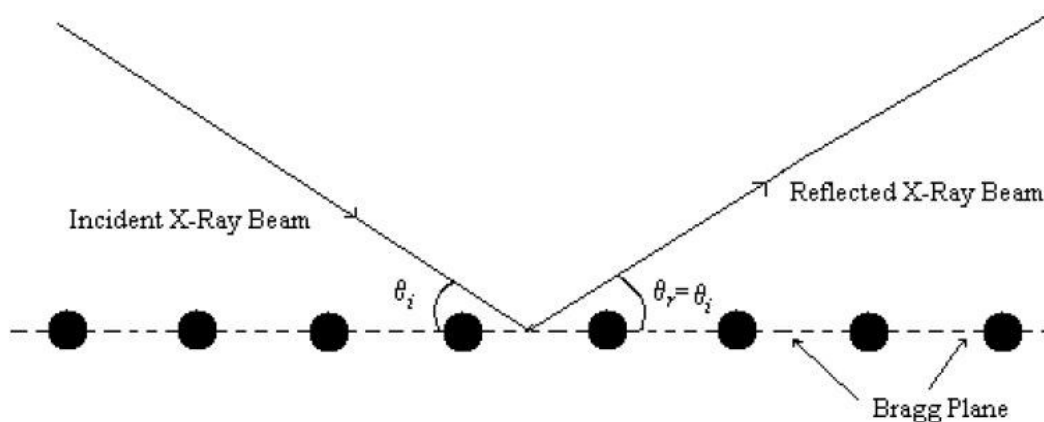

Fig. 6.2: X-Ray Reflection from a Bragg Plane

Reflection from successive planes can interfere constructively if the path difference between two rays is equal to an integral number of wavelengths. This statement is called Bragg's law.
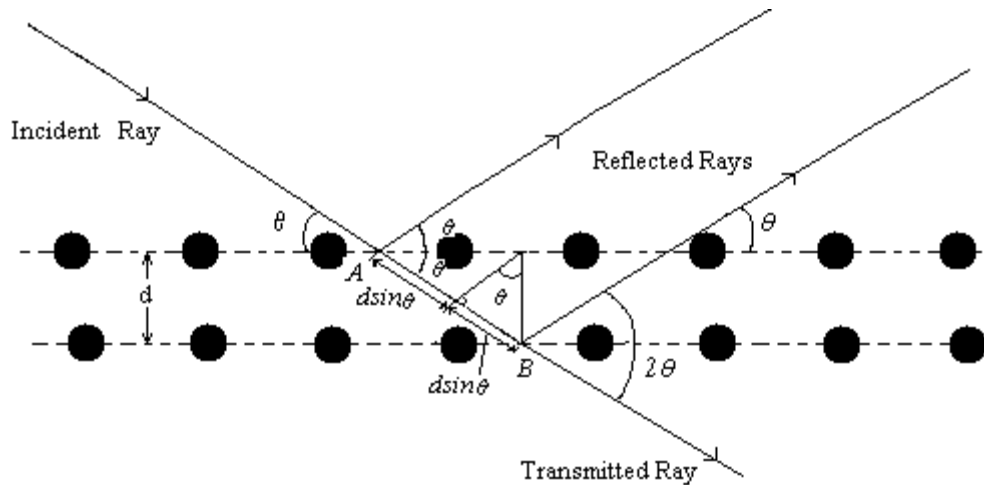

Fig. 6.3: Diffraction of X-Rays from Atomic Planes

From Fig. 4.8, AB = 2dsinθ so that by Bragg's law, we have

$$2d \sin\theta = n\lambda$$

Where in practice, it is normal to assume first order diffraction so that n = 1. A given set of atomic planes gives rise a reflection at one angle, seen as a spot or a ring in a diffraction pattern also called *a diffractogram*.

X-Rays — Multiple Choice Questions

1. X-rays were discovered by:

   (a) J.J. Thomson

   (b) W. C. Roentgen

   (c) Ernest Rutherford

   (d) Marie Curie

2. Roentgen discovered X-rays while experimenting with:

   (a) Alpha rays

   (b) Cathode rays

   (c) Gamma rays

   (d) Infrared radiation

3. The X-rays were named so because:

   (a) They were generated using X-tubes

   (b) Their nature was unknown

   (c) They were found in the X region of spectrum

   (d) They were produced by X-element

4. The first X-ray photograph taken by Roentgen was of:

   (a) His own hand

   (b) His wife's hand

   (c) A metal plate

   (d) A plant leaf

5. X-rays can pass through:

   (a) Metals only

   (b) Human tissue but not bones

   (c) Tissue, leaving bones visible

   (d) None of the above

6. The first X-ray tube was invented by:

   (a) William Crookes

   (b) James Clerk Maxwell

   (c) Robert Millikan

(d) Max Planck

7. The Crookes tube is also called a:

(a) Discharge tube

(b) Ionization chamber

(c) Geiger counter

(d) Cathode detector

8. The pressure inside an X-ray tube is approximately:

(a) 100 Pa

(b) 10^6 Pa

(c) 1 atm

(d) 10^{-6} Pa

9. The high voltage applied between the electrodes in an X-ray tube is typically:

(a) 3–15 kV

(b) 30–150 kV

(c) 300–1500 kV

(d) 1–10 V

10. The X-rays are produced when:

(a) Protons strike the target

(b) Electrons hit the anode target

(c) Neutrons hit the cathode

(d) Photons collide in vacuum

11. The main process responsible for X-ray production is called:

(a) Photoelectric effect

(b) Bremsstrahlung

(c) Compton scattering

(d) Pair production

12. The term *Bremsstrahlung* is of __ origin and means __.

(a) Greek; bright light

(b) German; braking radiation

(c) Latin; strong rays

(d) French; invisible waves

13. The X-ray spectrum from a tube consists of:

    (a) Continuous spectrum only

    (b) Line spectrum only

    (c) Both line and continuous spectra

    (d) Neither continuous nor line spectra

14. Which of the following is **not** a property of X-rays?

    (a) Travel in straight lines

    (b) Deflected by magnetic fields

    (c) Have high penetrating power

    (d) Produce ionization in gases

15. When X-rays strike fluorescent materials, they:

    (a) Stop glowing

    (b) Glow or fluoresce

    (c) Reflect light

    (d) Produce sound

16. The photographic film is affected by X-rays because:

    (a) X-rays heat the film

    (b) X-rays cause chemical reactions in the film

    (c) X-rays ionize silver atoms directly

    (d) Film is magnetic

17. The X-ray diffraction law given by Bragg is:

    (a) $2d \sin \theta = n\lambda$

    (b) $d = n\lambda \sin \theta$

    (c) $\lambda = d \sin \theta$

    (d) $n\lambda = 2\theta d$

18. In Bragg's law, d represents:

    (a) Distance between atomic planes

    (b) Wavelength of X-rays

    (c) Diffraction angle

(d) Path difference

19. Constructive interference of X-rays occurs when:

   (a) The phase difference is 180°
   (b) The path difference equals an integral multiple of λ
   (c) The path difference is half the wavelength
   (d) They are in random phase

20. The diffraction pattern observed in X-ray crystallography is often called a:

   (a) Radiograph
   (b) Spectrogram
   (c) Diffractogram
   (d) Thermogram