CLINICAL RADIATION GENERATORS

The Cyclotron

A **cyclotron** is a device that can accelerate charged particles to very high speeds. The energetic particles produced are used to bombard atomic nuclei and thereby produce nuclear reactions of interest to researchers. A number of hospitals use cyclotron facilities to produce radioactive substances for diagnosis and treatment. The power supply provides a rapidly alternating voltage across the dees (the two halves of the circle). This produces a rapidly alternating electric field between the dees that accelerates the particles, which quickly acquire high kinetic energies. They spiral outward under the influence of the magnetic field until they have sufficient velocity and are deflected into a target. Both electric and magnetic forces play key roles in the operation of a cyclotron, a schematic drawing of which is shown in Figure 1a, 1b.

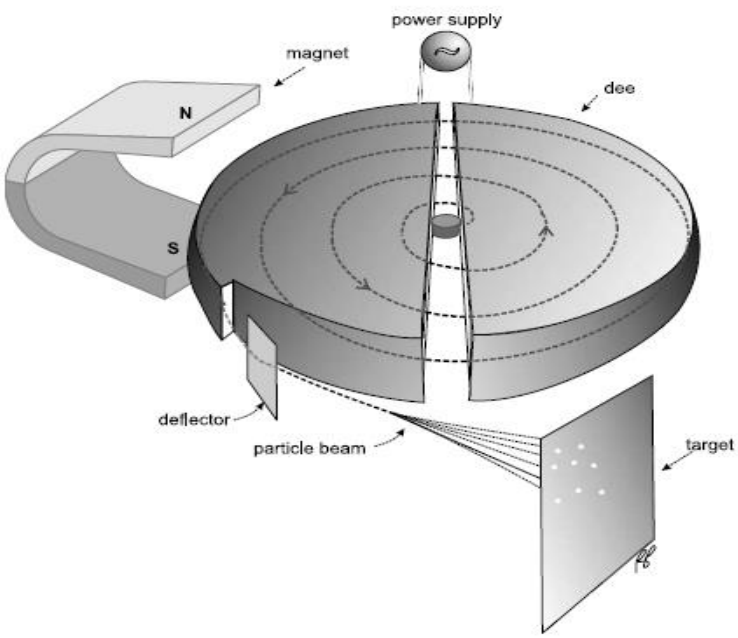

Figure 1: cyclotron

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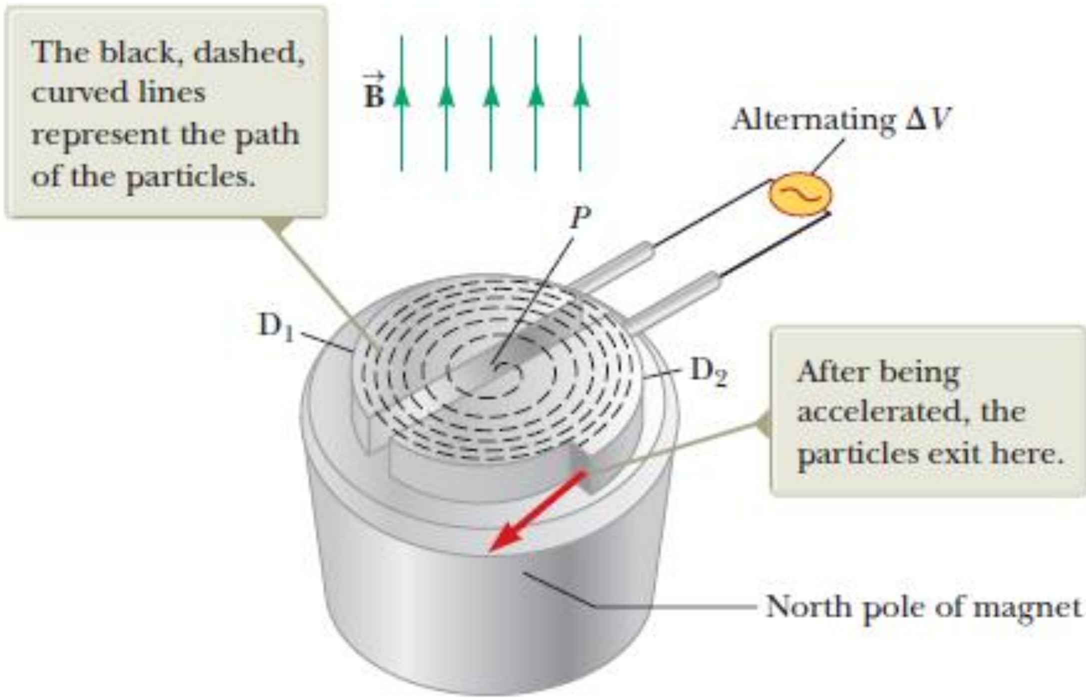

Figure 1b: A cyclotron consists of an ion source at P, D1 and D2 across which an alternating potential difference is applied, and a uniform magnetic field. (The south pole of the magnet is not shown.)

A deflector is used to direct the particles out through a window of the cyclotron into a **target**. Some of the particles and kinetic energy from these particles are incorporated into the nuclei of the atoms of the target. These energized (excited)

nuclei are unstable. Indium-111 (**^{111}In**) is produced in a cyclotron.

The accelerated (bombarding) particles are protons. The target atoms are cadmium-111 (**^{111}Cd**). When a proton enters the nucleus of a **^{111}Cd** atom, the **^{111}Cd** is transformed into ^{111}**In** by discharging a neutron. This reaction can be written as:

Target atom (bombarding particle, emitted particle) product nuclide, Cadmium-111(proton, neutron)Indium-111,

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- The charges move inside two semicircular containers D_1 and D_2.
- A high-frequency alternating potential difference is applied to the D_1, D_2, and a uniform magnetic field is directed perpendicular to them.
- A positive ion released at *P* near the center of the magnet in one D moves in a semicircular path (indicated by the dashed black line in the drawing).
- And arrives back at the gap in a time interval $T/2$, where T is the time interval needed to make one complete trip around the two D, given by Equation 1.

$$T = \frac{2\pi r}{v} = \frac{2\pi}{\omega} = \frac{2\pi m}{qB} \qquad \text{eq.1}$$

- The frequency of the applied potential difference is adjusted so that the polarity of the D is **reversed** in the same time interval during which the ion travels around one D.
- If the applied potential difference is adjusted such that D_1 is at a lower electric potential than D_2 by an amount ΔV, the ion accelerates across the gap to D1 and its kinetic energy increases by an amount $q\,\Delta V$.
- It then moves around D1 in a semicircular path of greater radius (because its speed has increased).
- After a time interval $T/2$, it again arrives at the gap between the D. By this time, the polarity across the D **has again been reversed** and the ion is given another "kick" across the gap.
- The motion continues so that for each half-circle trip around one D, the ion gains additional kinetic energy equal to $q\,\Delta V$.
- When the radius of its path is nearly that of the D, the energetic ion leaves the system through the exit slit.
- The cyclotron's operation depends on **T** being independent of the speed of the ion and of the radius of the circular path.
- We can obtain an expression for the kinetic energy of the ion when it exits the cyclotron in terms of the radius R of the D , we know that $\upsilon = qBR/m$. Hence, the kinetic energy is:

$$K = \frac{1}{2}mv^2 = \frac{q^2B^2R^2}{2m}$$

** mυ linear momentum of the particle

** q magnitude of the charge on the particle

** B the magnitude of the magnetic field.

When the energy of the ions in a cyclotron exceeds about 20 MeV, relativistic

effects come into play. Observations show that T increases and the moving ions do not remain in phase with the applied potential difference. Some accelerators overcome this problem by modifying the period of the applied potential difference so that it remains in phase with the moving ions.

Medical application of cyclotron:

- used to generate high energy protons and heavy ions for therapy.
- used to accelerate deuterons to produce neutrons.
- used for the production of radionuclide.

The Van de Graaff generator

A Van de Graaff generator is an electrostatic generator which uses a moving belt to accumulate very high amounts of electrical potential on a hollow metal globe on the top of the stand. Experimental results show that when a charged conductor is placed in contact with the inside of a hollow conductor, all the charge on the charged conductor is transferred to the hollow conductor. In principle, the charge on the hollow conductor and its electric potential can be increased without limit by repetition of the process.

In 1929, Robert J. Van de Graaff (1901–1967) used this principle to design and build an electrostatic generator, and a schematic representation of it is given in Figure 3. This type of generator was once used extensively in nuclear physics research.

- Charge is delivered continuously to a high-potential electrode by means of a moving belt of insulating material.
- The high-voltage electrode is a hollow metal dome mounted on an insulating column.
- The belt is charged at point **A** by means of a corona discharge between comb-like metallic needles and a grounded grid.
- The needles are maintained at a positive electric potential of typically 10^4 V.
- The positive charge on the moving belt is transferred to the dome by a second comb of needles at point **B**.
- Because the electric field inside the dome is negligible, the positive charge on the belt is easily transferred to the conductor regardless of its potential.
- In practice, it is possible to increase the electric potential of the dome until electrical discharge occurs through the air. Because the "breakdown" electric field in air is about $3 * 10^6$ V/m, a sphere 1.00 m in radius can be raised to a maximum potential of $3 * 10^6$ V.
- The potential can be increased further by increasing the dome's radius and placing the entire system in a container filled with high-pressure gas.
- Van de Graaff generators can produce potential differences as large as 20 million volts.
- Protons accelerated through such large potential differences receive enough energy to initiate nuclear reactions between themselves and various target nuclei.
- Smaller generators are often seen in science classrooms and museums. If a person insulated from the ground touches the sphere of a Van de Graaff generator, his or her body can be brought to a high electric potential.

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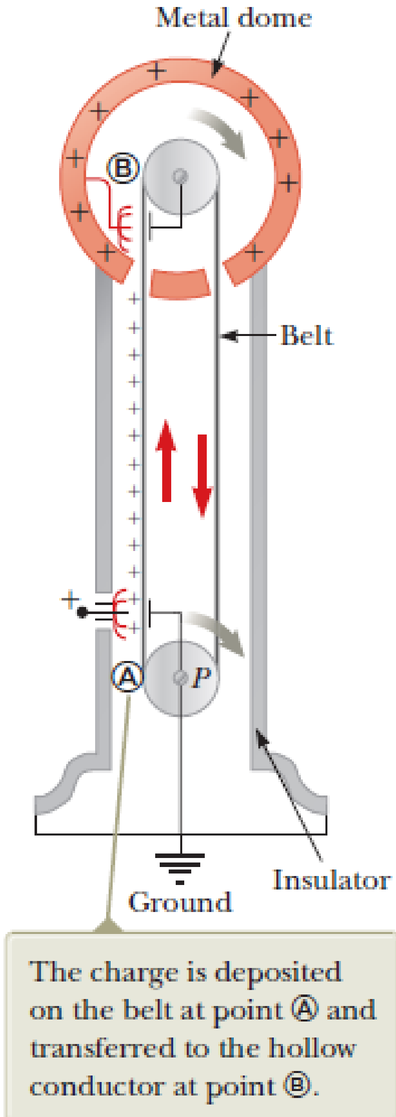

Figure 1 Schematic diagram of a Van de Graaff generator. Charge is transferred to the metal dome at the top by means of a moving belt.

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