elements such as selenium, silicon, and germanium. These semiconductors conduct electrons in one direction only and can withstand reverse voltage up to a certain magnitude. Because of their very small size, thousands of these rectifiers can be stacked in series in order to withstand the given inverse voltage.

Rectifiers can also be used to provide *full-wave* rectification. For example, four rectifiers can be arranged in the high voltage part of the circuit so that the x-ray tube cathode is negative and the anode is positive during both half-cycles of voltage. This is schematically shown in Fig. 3.5. The electronic current flows through the tube via ABCDEFGH when the transformer end A is negative and via HGCDEFBA when A is positive. Thus, the electrons flow from the filament to the target during both half-cycles of the transformer voltage. As a result of full wave rectification, the effective tube current is higher since the current flows during both half-cycles.

In addition to rectification, the voltage across the tube may be kept nearly constant by a smoothing condenser (high capacitance) placed across the x-ray tube. Such constant potential circuits are commonly used in x-ray machines for therapy.

3.4 PHYSICS OF X-RAY PRODUCTION

There are two different mechanisms by which x-rays are produced. One gives rise to *bremsstrahlung x-rays* and the other *characteristic x-rays.* These

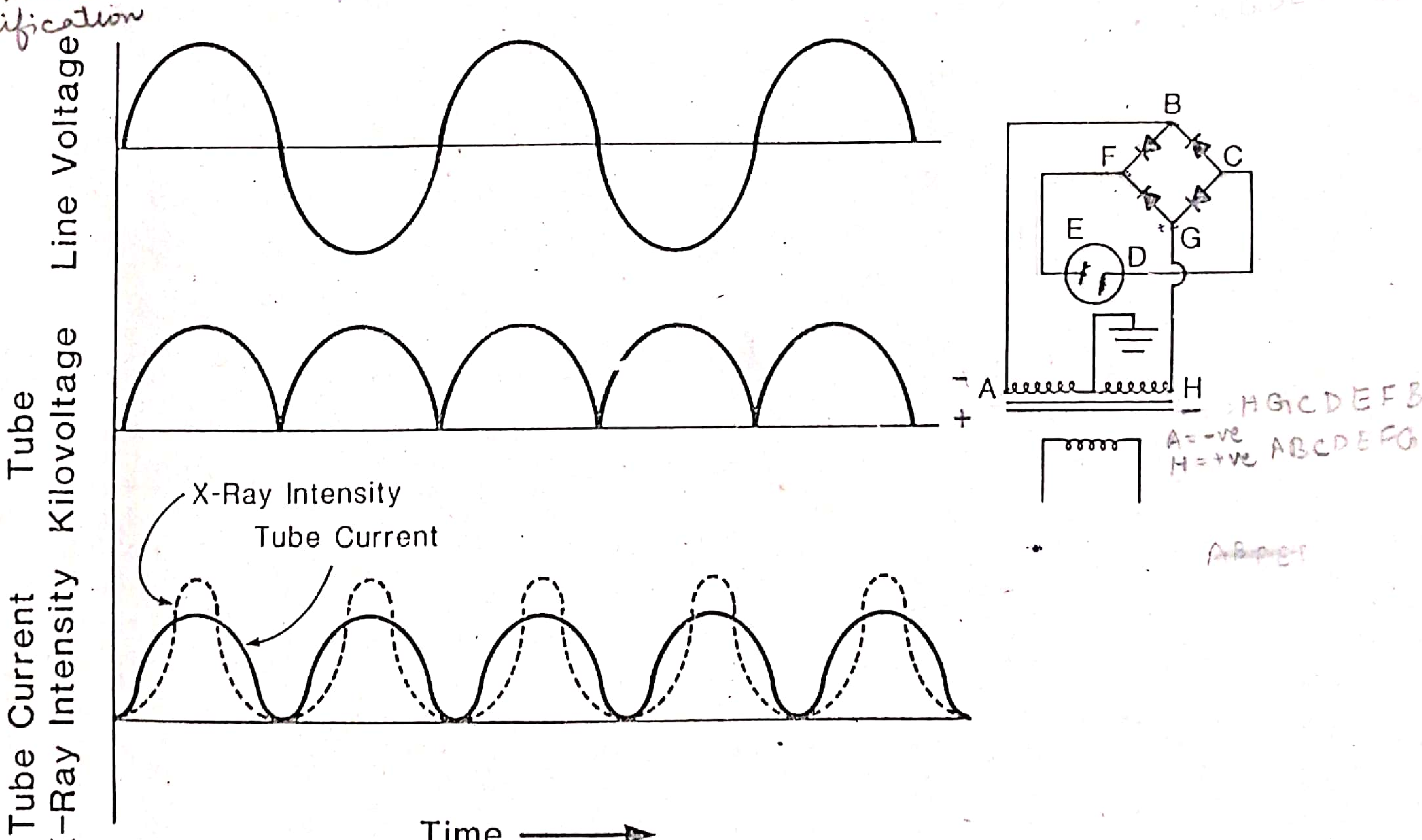

Figure 3.5. Graphs illustrating the variation with time of the line voltage, the tube kilovoltage, the tube current, and the x-ray intensity for full-wave rectification. The rectifier circuit is shown on the right. The arrow symbol of the rectifier indicates the direction of conventional current flow (opposite to the flow of electronic current).

processes were briefly mentioned earlier (Sections 1.5 and 3.1) but now will be presented in greater detail.

A. Bremsstrahlung

The process of bremsstrahlung (braking radiation) is the result of radiative "collision" (interaction) between a high speed electron and a nucleus. The electron while passing near a nucleus may be deflected from its path by the action of Coulomb forces of attraction and lose energy as bremsstrahlung, a phenomenon predicted by Maxwell's general theory of electromagnetic radiation. According to this theory, energy is propagated through space by electromagnetic fields. As the electron, with its associated electromagnetic field, passes in the vicinity of a nucleus, it suffers a sudden deflection and acceleration. As a result, a part or all of its energy is dissociated from it and propagates in space as electromagnetic radiation. The mechanism of bremsstrahlung production is illustrated in Fig. 3.6.

Since an electron may have one or more bremsstrahlung interactions in the material and an interaction may result in partial or complete loss of electron energy, the resulting bremsstrahlung photon may have any energy up to the initial energy of the electron. Also, the direction of emission of bremsstrahlung photons depends on the energy of the incident electrons (Fig. 3.7). At electron energies below about 100 keV, x-rays are emitted more or less equally in all directions. As the kinetic energy of the electrons increases, the direction of x-ray emission becomes increasingly forward. Therefore, *transmission-type targets* are used in megavoltage x-ray tubes (accelerators) in which the electrons bombard the target from one side and the x-ray beam is obtained on the other side. In the low voltage x-ray tubes, it is technically advantageous to obtain the x-ray beam on the same side of the target, *i.e.* at 90° with respect to the electron beam direction.

The energy loss per atom by electrons depends upon the square of the atomic number (Z^2). Thus, the probability of bremsstrahlung production varies with Z^2 of the target material. However the efficiency of x-ray production depends on the first power of atomic number and the voltage applied to the tube. The term efficiency is defined as the ratio of output energy emitted as

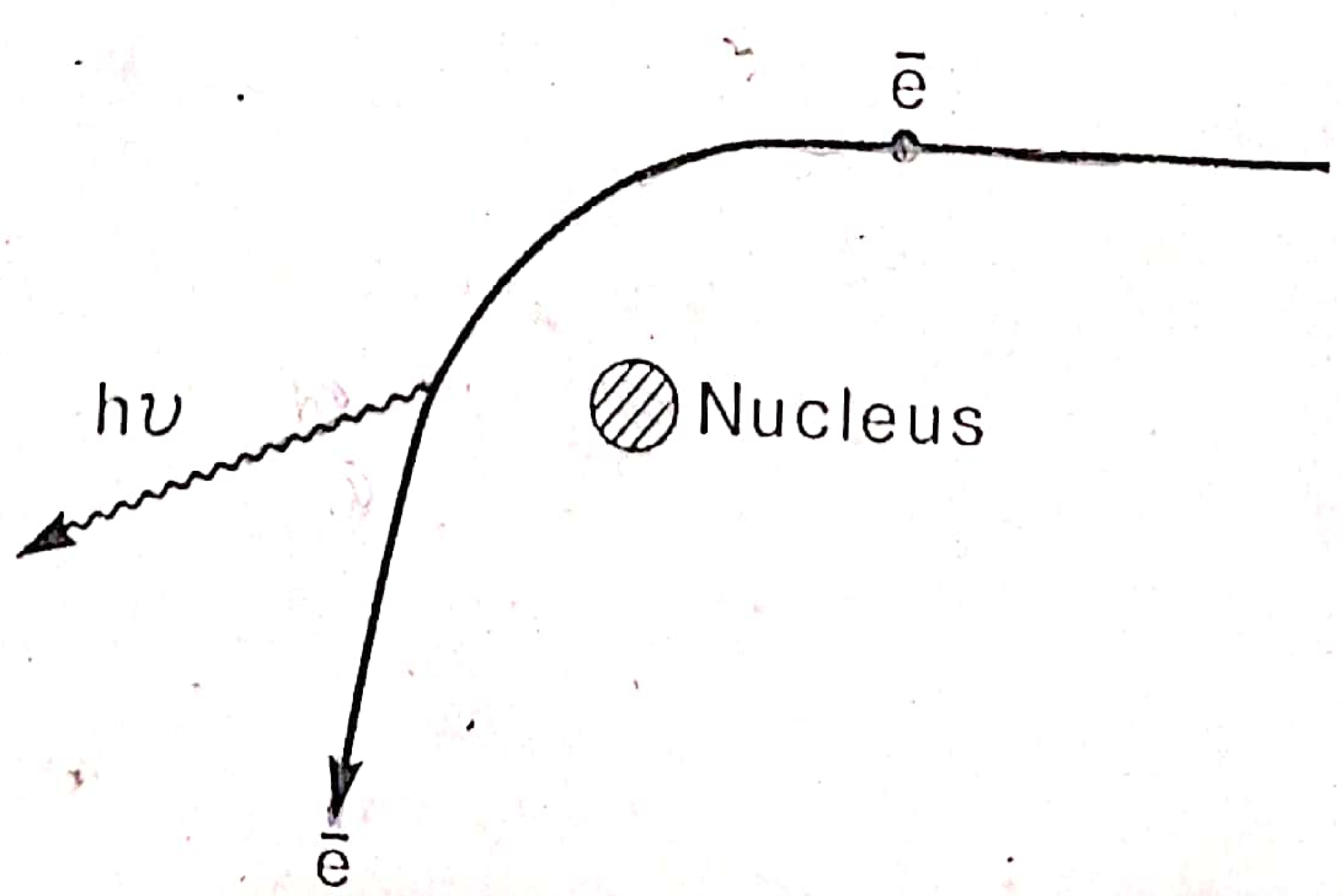

Figure 3.6. Illustration of bremsstrahlung pro...