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Non-radioactive radiation sources

FYS-KJM 4710

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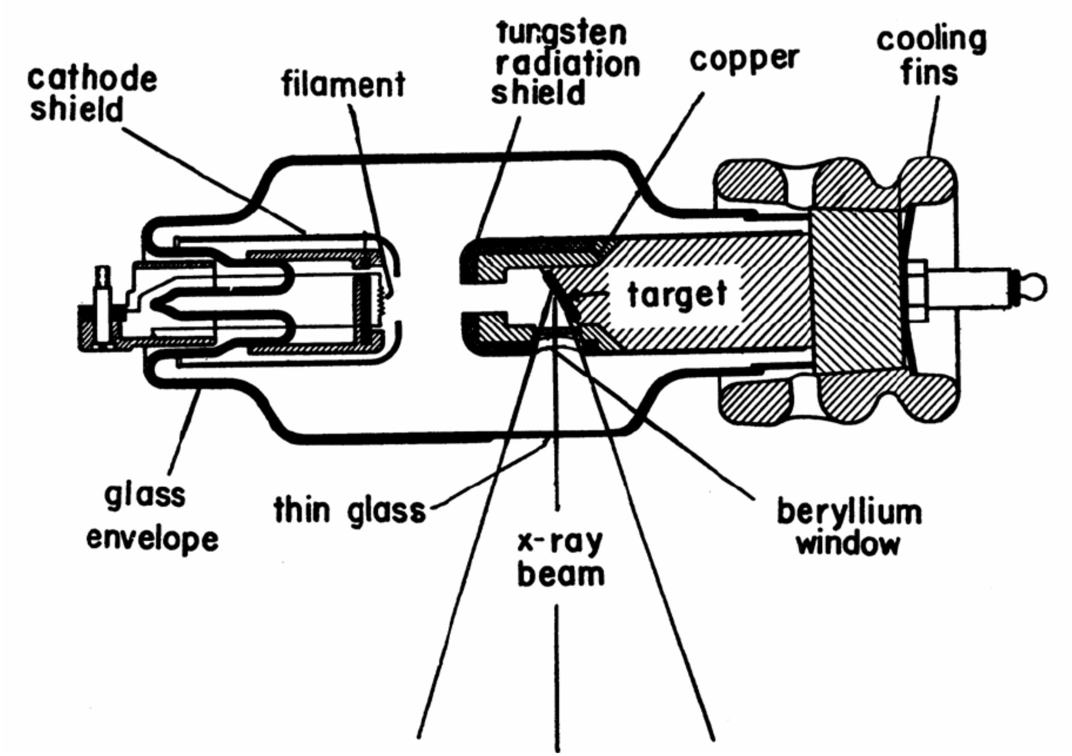
X-ray tube

- Electrons are released from the cathode (negative electrode) by thermal emission – accelerated in an evacuated tube – hit the anode (target, positive electrode) – bremsstrahlung is generated:



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X-ray tube and radiation

- Target and filament, mostly tungsten
- X-ray radiation: in fact denoting all photon generated from electrons slowing down
- Power P=V x I; unit kW
- Radiation yield:

Energy out as X-ray radiation/Energy inn ~ 0.1% – 2%

for 10keV – 200keV electrons (increasing with kinetic energy) in tungsten

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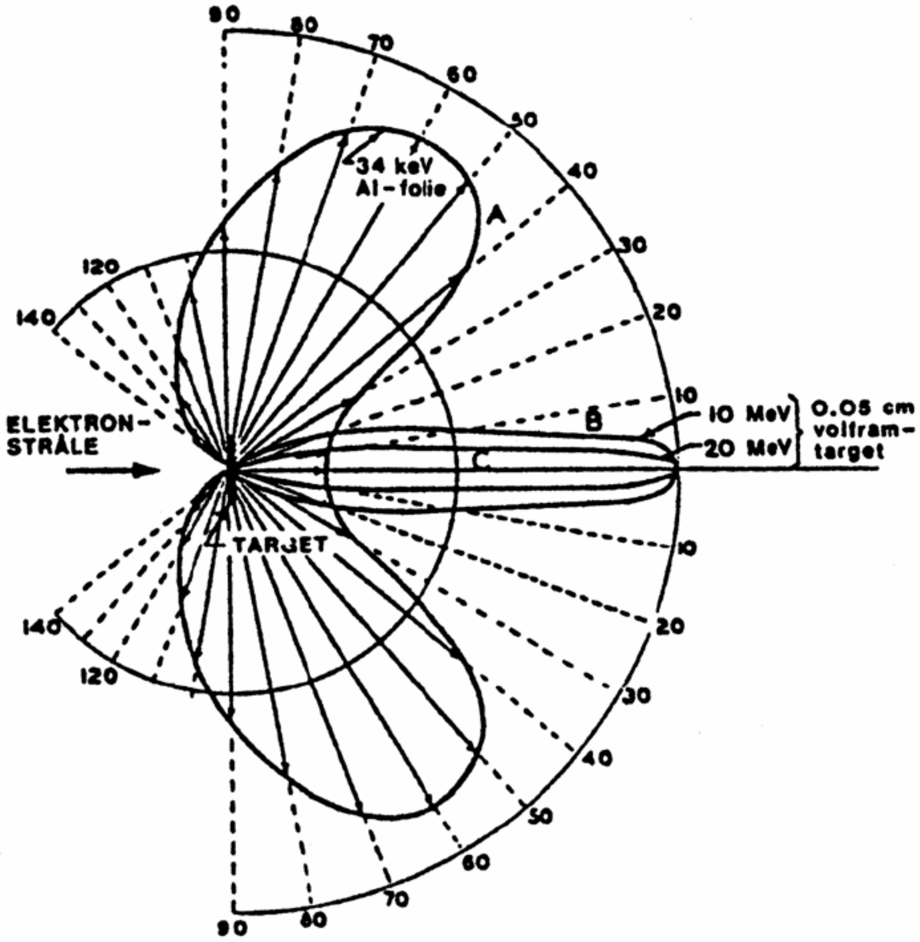
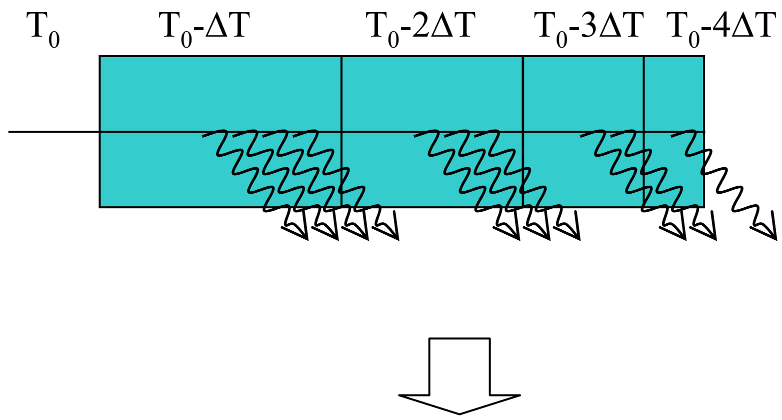
X-rays – direction characteristic

- Direction of the emitted photons dependent mostly of electron energy:



Kramers rule 1)

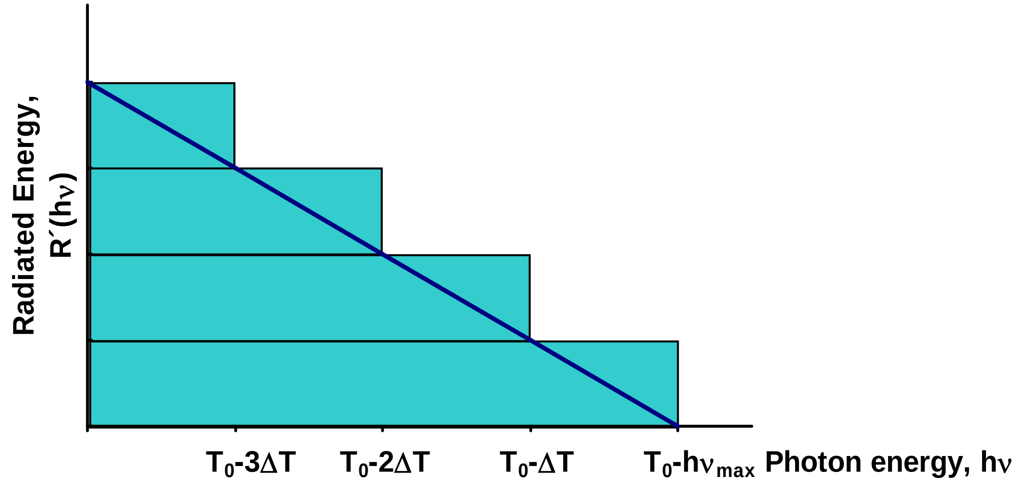
- Unfiltered (energy fluence-) spectrum is given from Kramers rule:



When $T_0 < m_e c^2$:

$$\left(\frac{dT}{dx}\right)_{rad} \approx \text{const.}$$

$$\left(\frac{dT}{dx}\right)_{col} \propto \frac{1}{T}$$



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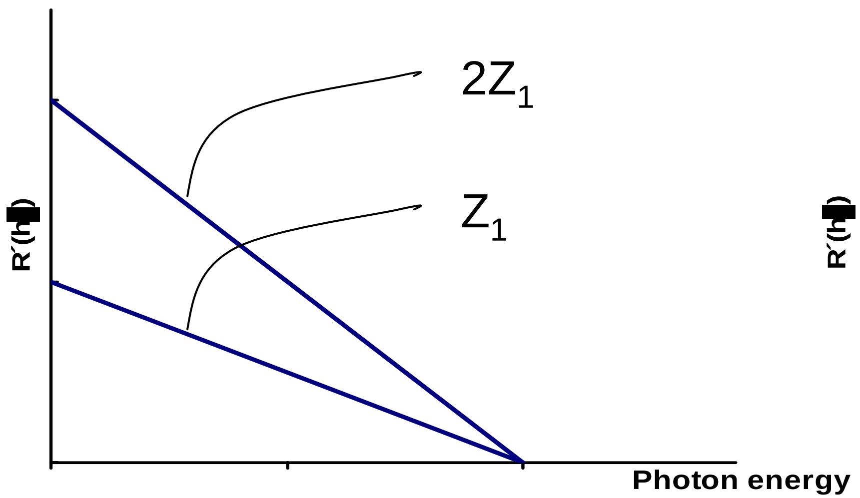
Kramers rule 2)

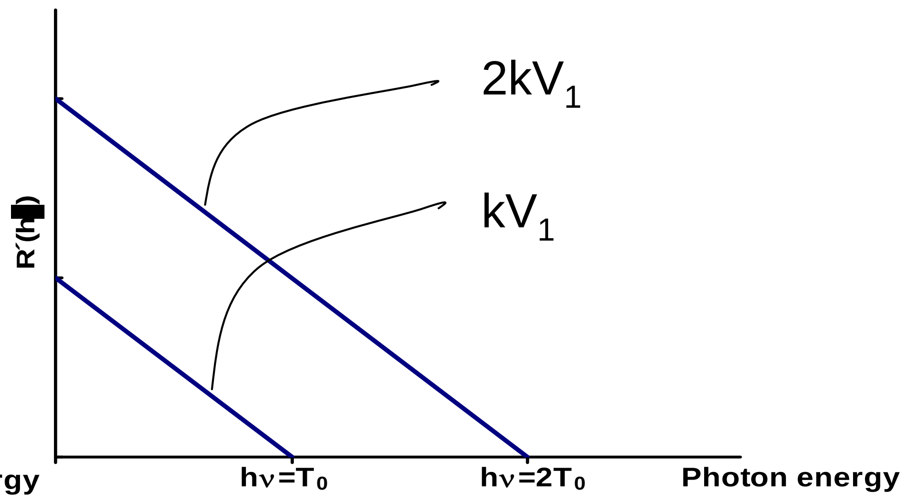
- Kramers spectrum: $R'(h\nu) = CN_eZ(h\nu_{max} - h\nu)$

Differential radiant-energy spectral distribution of bremsstrahlung generated in the thick target of atomic number Z, $h\nu_{max} = T_0$, is the maximum photon energy.

Dependents of
the atom number



Dependents of
the X-ray potential



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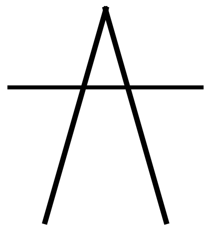
Filtering and the X-ray spectrum

- Filtering modify the spectrum, both in intensity and characterization



Filter

Attenuation coefficient μ

Thickness x

- Each photon is attenuated with a probability $e^{-\mu x}$, where μ depend of energy and filter medium
- Low energetic (“soft”) X-ray radiation attenuated most
- X-ray spectrum is more homogenous with more “hard” filtering

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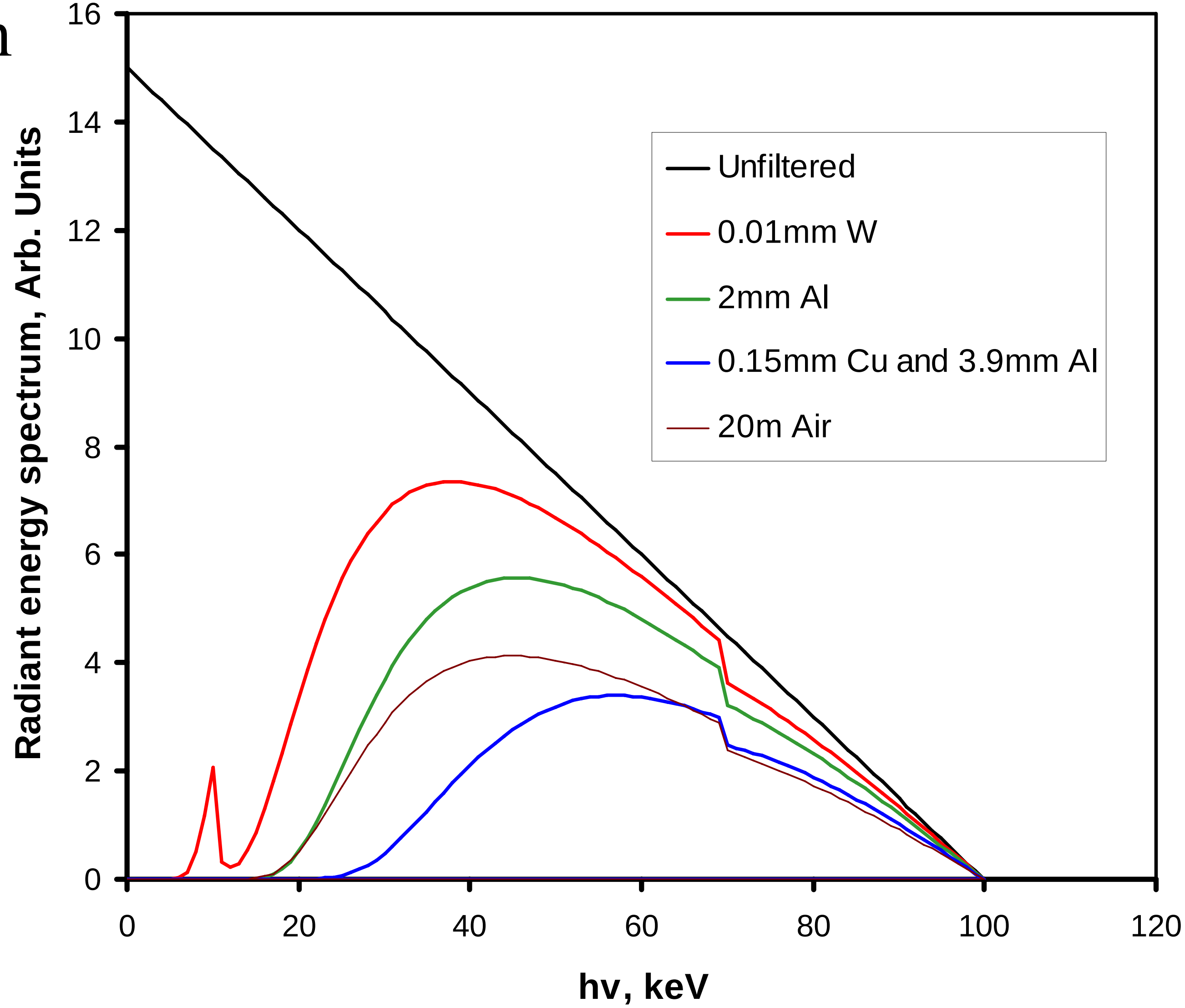
X-ray spectrum Example Fig 9.10

- X-Ray spectrum from 100-keV electrons on a thick tungsten target



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Spectrometry

- Measurement of radiation spectrum
- Pulse- height analysis by:
  - Scintillation counter, (NaI(Tl)):

    Light is emitted at irradiation – intensity ("height") of light pulse proportional with quantum energy – number of pulses at each pulse height gives intensity of the given energy interval
  - Semiconductor (Ge(Li)):

    Current pulse trough *p*-*n*- junction at irradiation – height of pulse proportional with quantum energy. Best, but most be cold with liquied N_2

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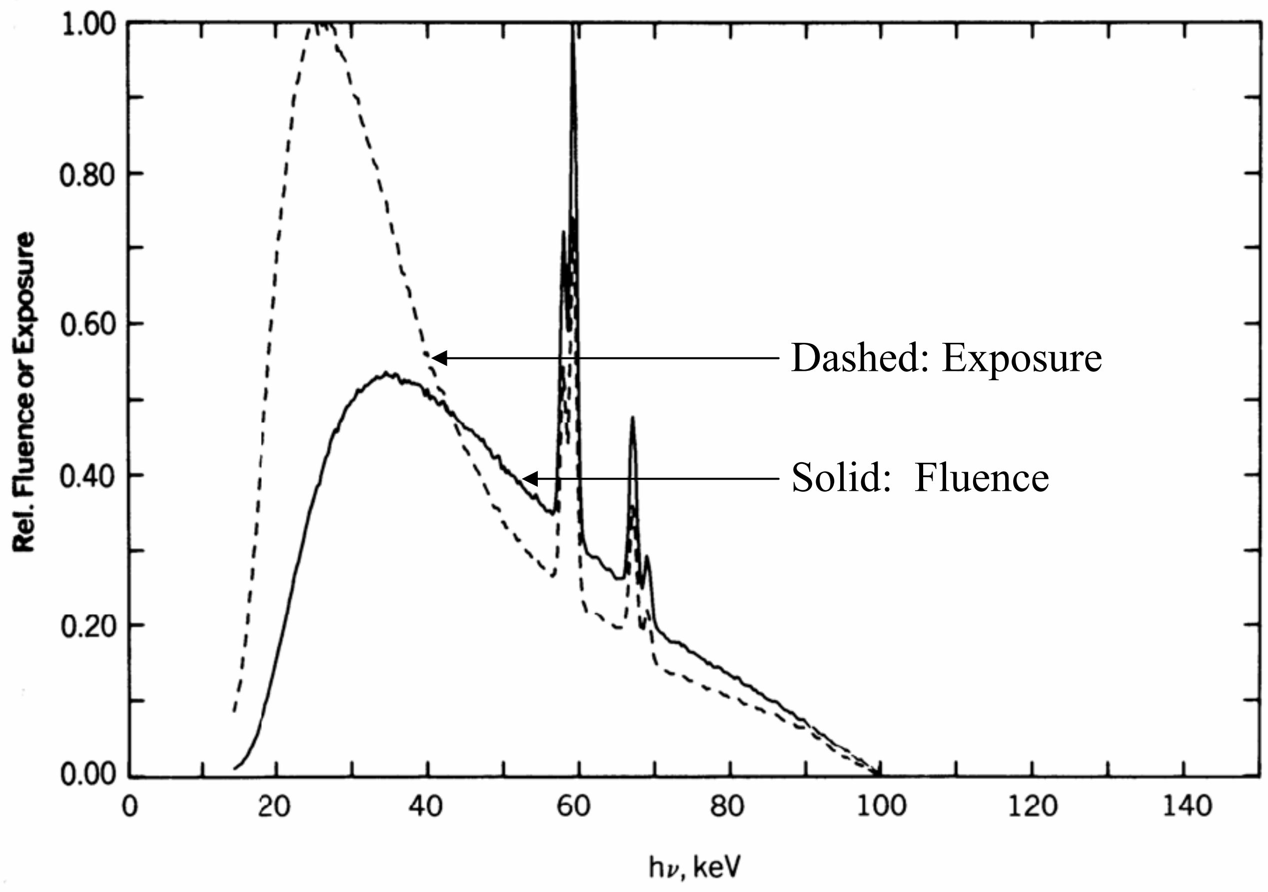
X-ray spectrum

- Example: 100 kV voltage, 2.0 mm Al-filter
- Average energy ~ 46 keV



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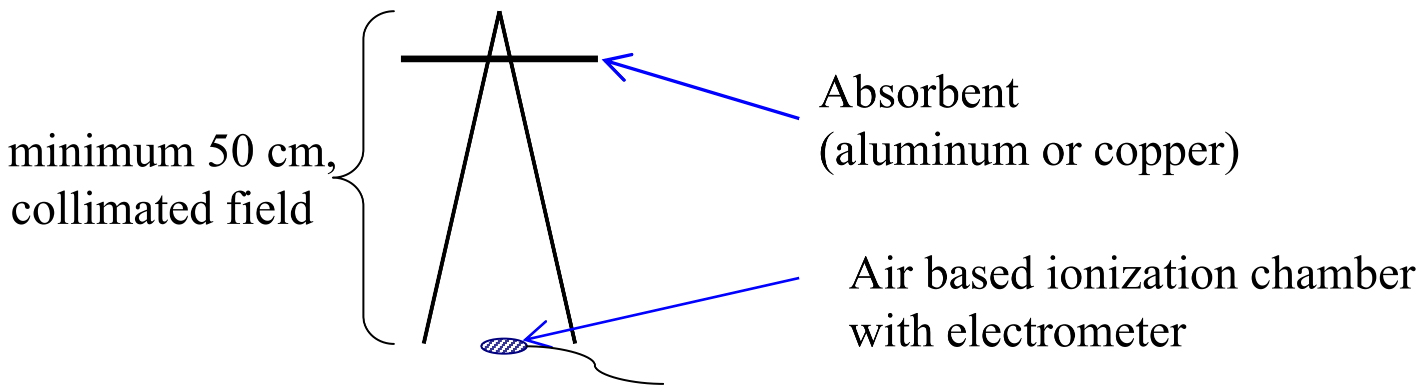
X-ray quality

- X-ray spectra gives most detailed characterization
- But: spectrometry is expensive, time demanding
- *Half value layer* the recommended standard



HVL: thickness of absorbent which reduces the exposure (~absorbed dose to air) with 50 %

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Half value layer - HVL

- Exponential attenuation of photons give:

$$N = N_0 e^{-\mu x}$$

$$N = \frac{N_0}{2} = N_0 e^{-\mu HVL}$$

$$\Rightarrow HVL = \frac{\ln 2}{\mu}$$

- X-ray quality is often given as half value layer in aluminum an copper

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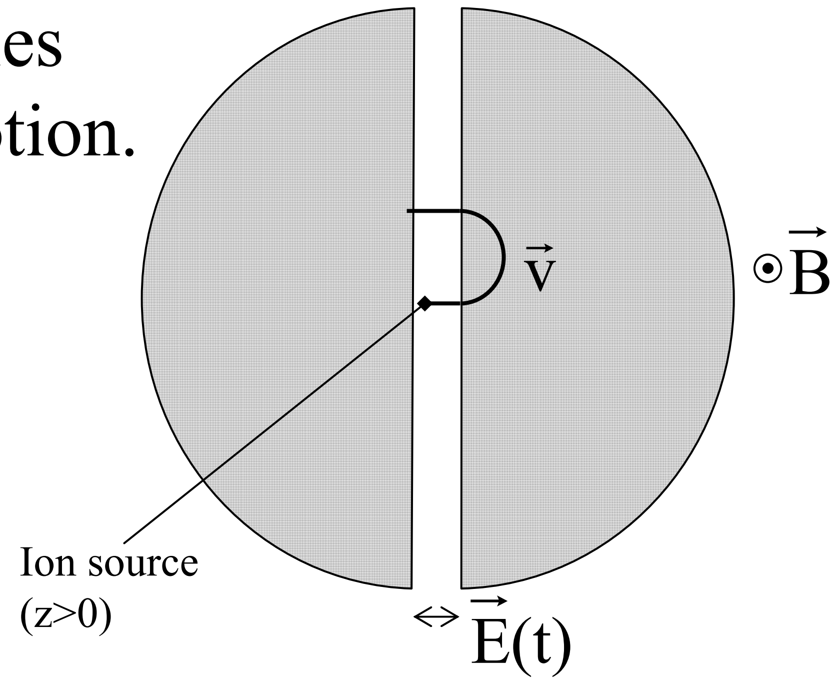
Cyclotron

- Acceleration of charged particles which are kept in a circular motion.
- Two part D-structure
- Time dependent voltage between the two D
- Two accelerations per cycles
  - period synchronized with voltage
- No good principle for acceleration of electrons an other light particles



Cyclotron – description 1)

- Particles is rotated 180º with a B-field, but accelerated by a time depending potential (kV/MHz)
- Potential V gives: $T = zV = \frac{1}{2}mv^2 \Rightarrow v^2 = \frac{2zZ}{m}$
- Combined with the Lorentz force: $(\vec{F} = z\vec{v} \times \vec{B})$

$$|F| = zvB = ma = \frac{mv^2}{r} \Rightarrow v^2 = \left(\frac{zBr}{m}\right)^2$$

$$\frac{2zV}{m} = \left(\frac{zBr}{m}\right)^2 \Rightarrow r^2 = \frac{2mV}{zB^2}$$

- Stronger magnetic field; larger ability of acceleration

- Radius increases with mass

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Cyclotron – description 2)

- The period Γ of a charged particle I a circular motion is:

$$\Gamma = \frac{2\pi r}{v} \quad , \quad v = \frac{zBr}{m}$$

$$\Rightarrow \quad \Gamma = \frac{2\pi m}{zB}$$

- Γ is then independent of the speed but:
- m is relativistic mass and increase with the speed:

$$m = \gamma m_0 \quad , \quad \gamma = (1-\beta^2)^{-1/2} \quad , \quad \beta = v/c$$

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Cyclotron – description 3)

- When the speed increase will the period Γ increase
- Conservation of energy (T_b and T_a: kinetic energy before and after acceleration):

$$T_a = T_b + zV \quad , \quad V = \int \vec{E} \times d\vec{l} \quad , \quad T = (\gamma - 1) m_0 c^2$$

$$\Rightarrow \ (\gamma_a - 1) m_0 c^2 = (\gamma_b - 1) m_0 c^2 + zV$$

$$\Rightarrow \ \gamma_a = \gamma_b + \frac{zV}{m_0 c^2}$$

$$\Rightarrow \ \Gamma = \frac{2\pi m}{zB} = \frac{2\pi \gamma_a m_0}{zB} = \frac{2\pi m_0}{zB}\left(\gamma_b + \frac{zV}{m_0 c^2}\right)$$

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Cyclotron – description 4)

- Rise in period proportional with zV/m_0c^2
- Example: zV = 100 keV
- Proton: $zV/m_pc^2 \sim 0.01$ %
- Electron: $zV/m_ec^2 \sim 20$ % → close to 50 % rise in one round → Time dependent E-field will have the wrong direction in relation to movement of the electron
- The E-field frequency can be synchronized with the rise in period → *synchrocyclotron / synchrotron*

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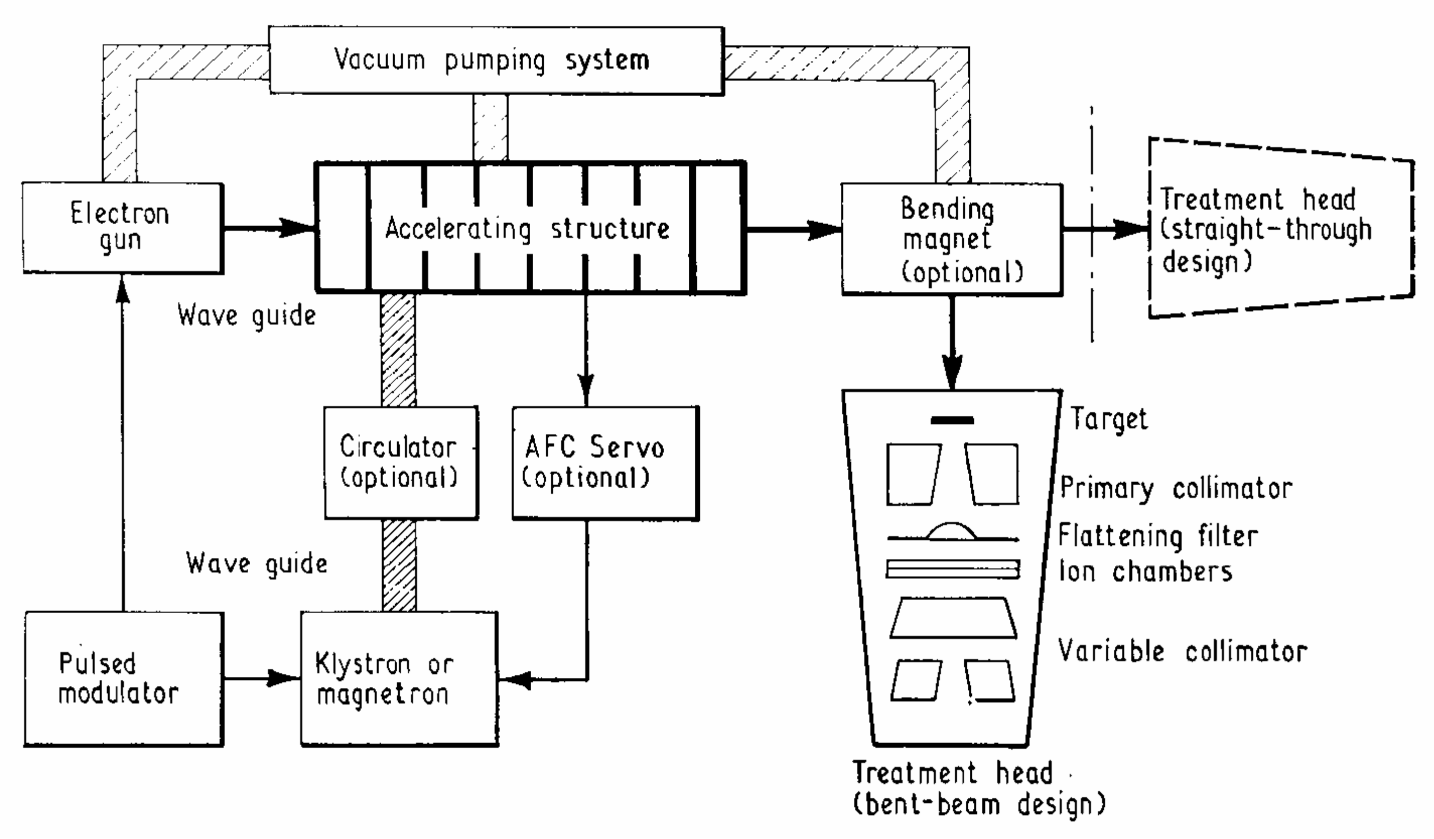
Linear-accelerator 1)

- Acceleration of charged particles in strong microwave field (~ Ghz):



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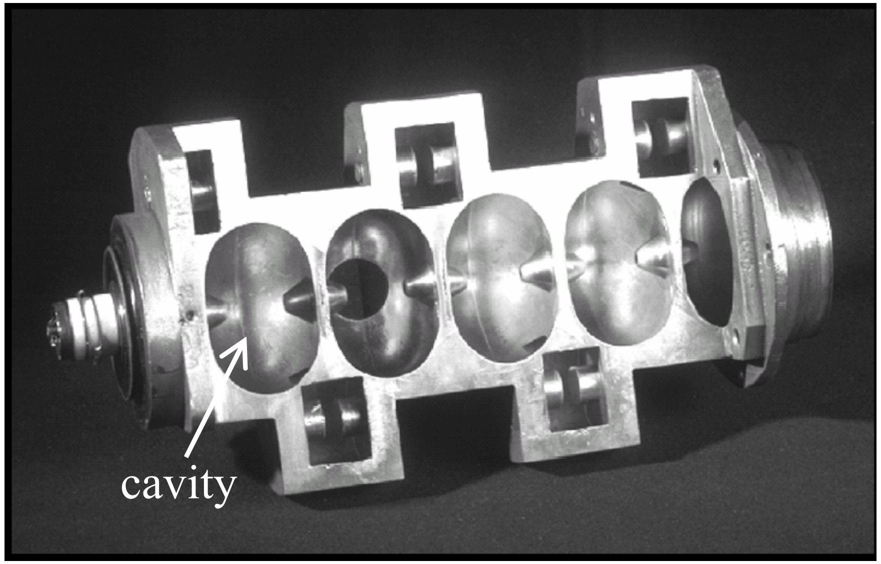
Linear-accelerator 2)

- Effective acceleration potential ~ MV
- Electron gets close to light speed after acceleration in one cavity

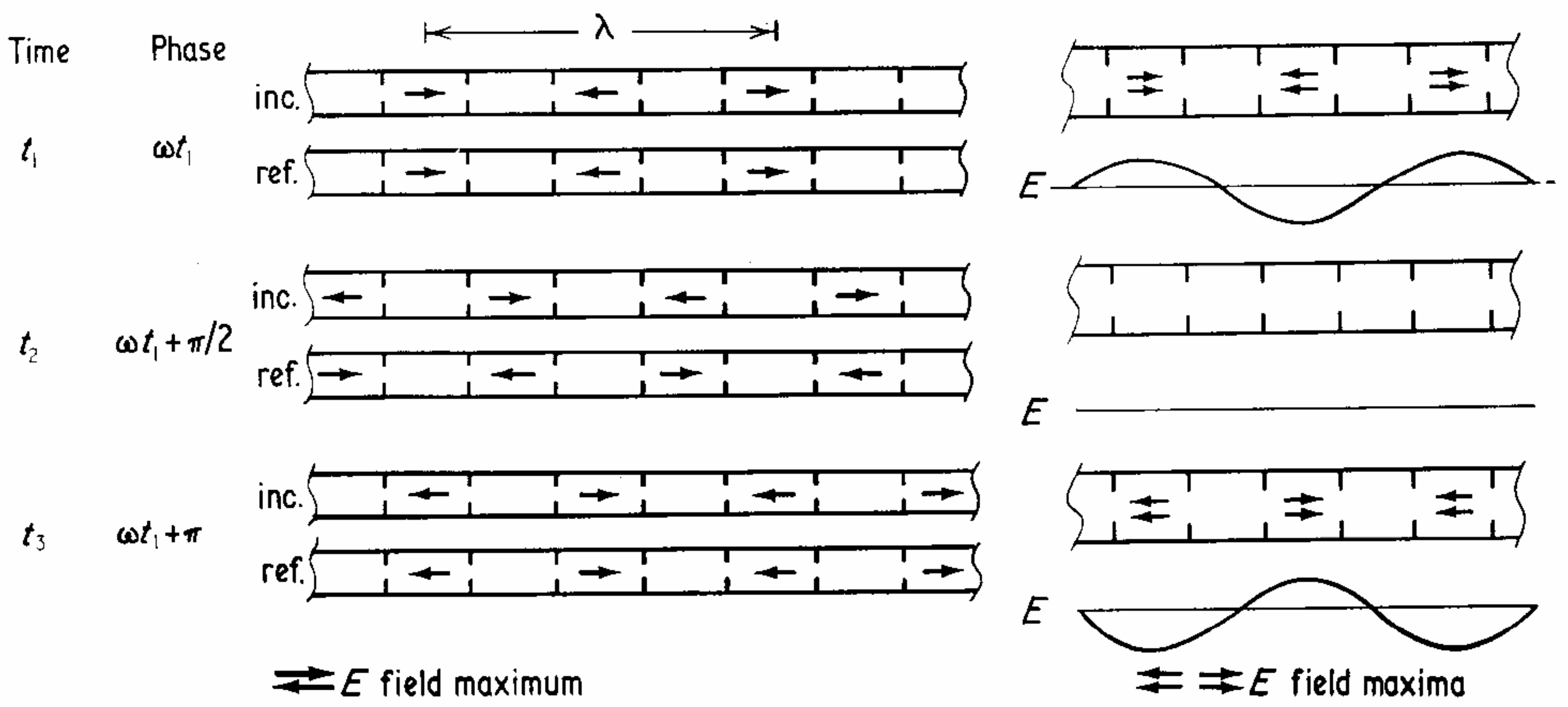


Acceleration tube
Effective potential: 6MV

- Electron can hit a target (ex. Tungsten) – high energetic bremsstrahlung generated

Acceleration tube

- Standing waves makes the electron "surf" on a wave of the electric field
- The amplitude decide the effective acceleration potential



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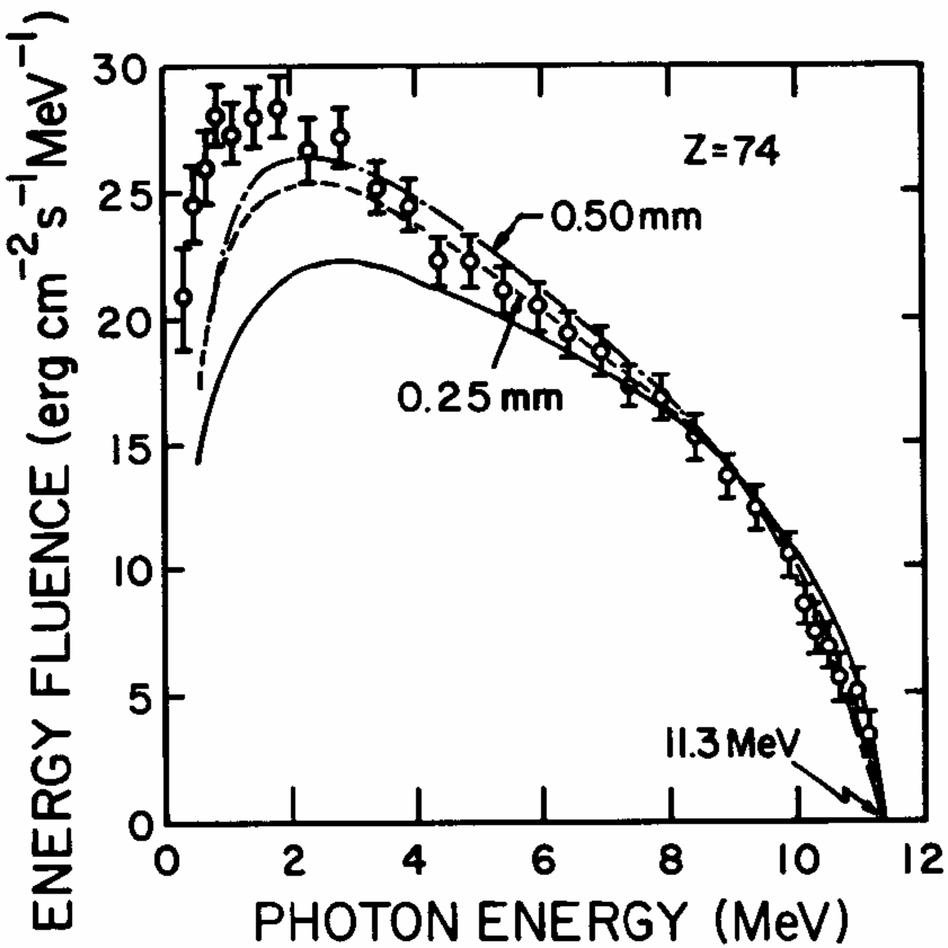
Photon spectrum

- Different characteristic than from the X-ray tube



11.3 MeV electrons against 1.5 mm tungsten target.
Lines: models of variation thickness of the target

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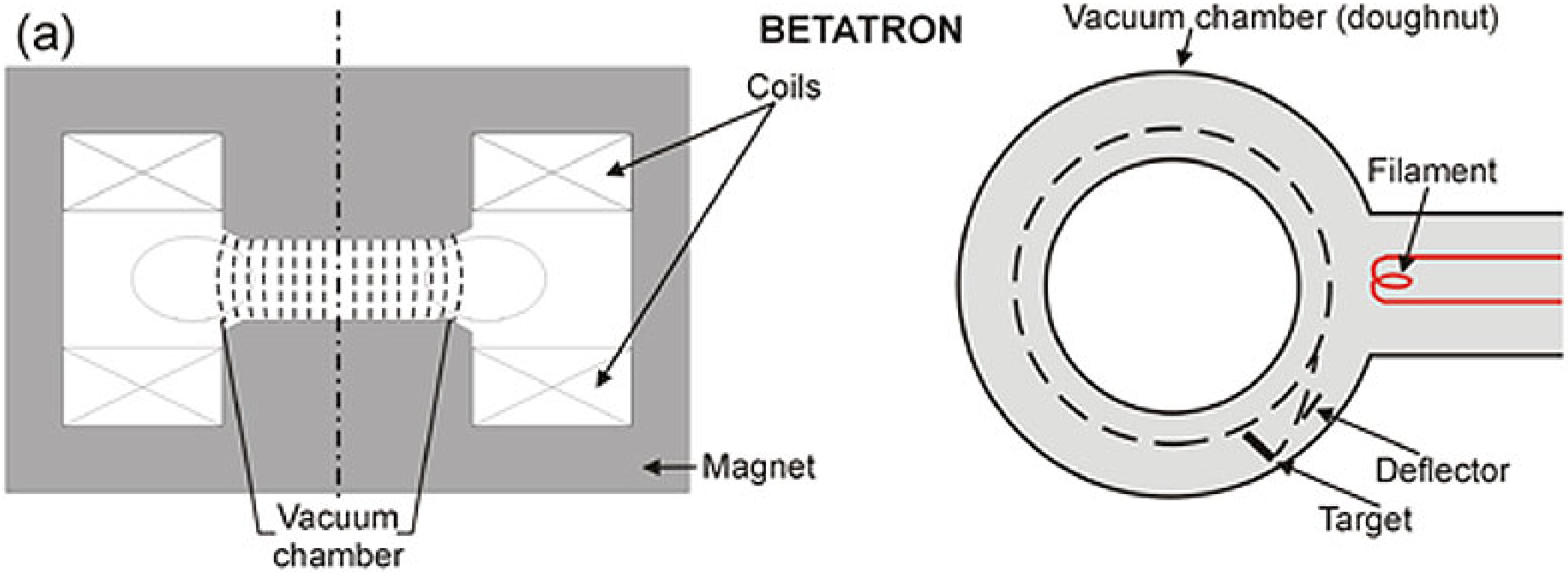
Betatron

- Charged particle (electron) accelerated in doughnut shaped unit:



- Time dependent magnetic field used to accelerate the electron and to make the electron move in a circle

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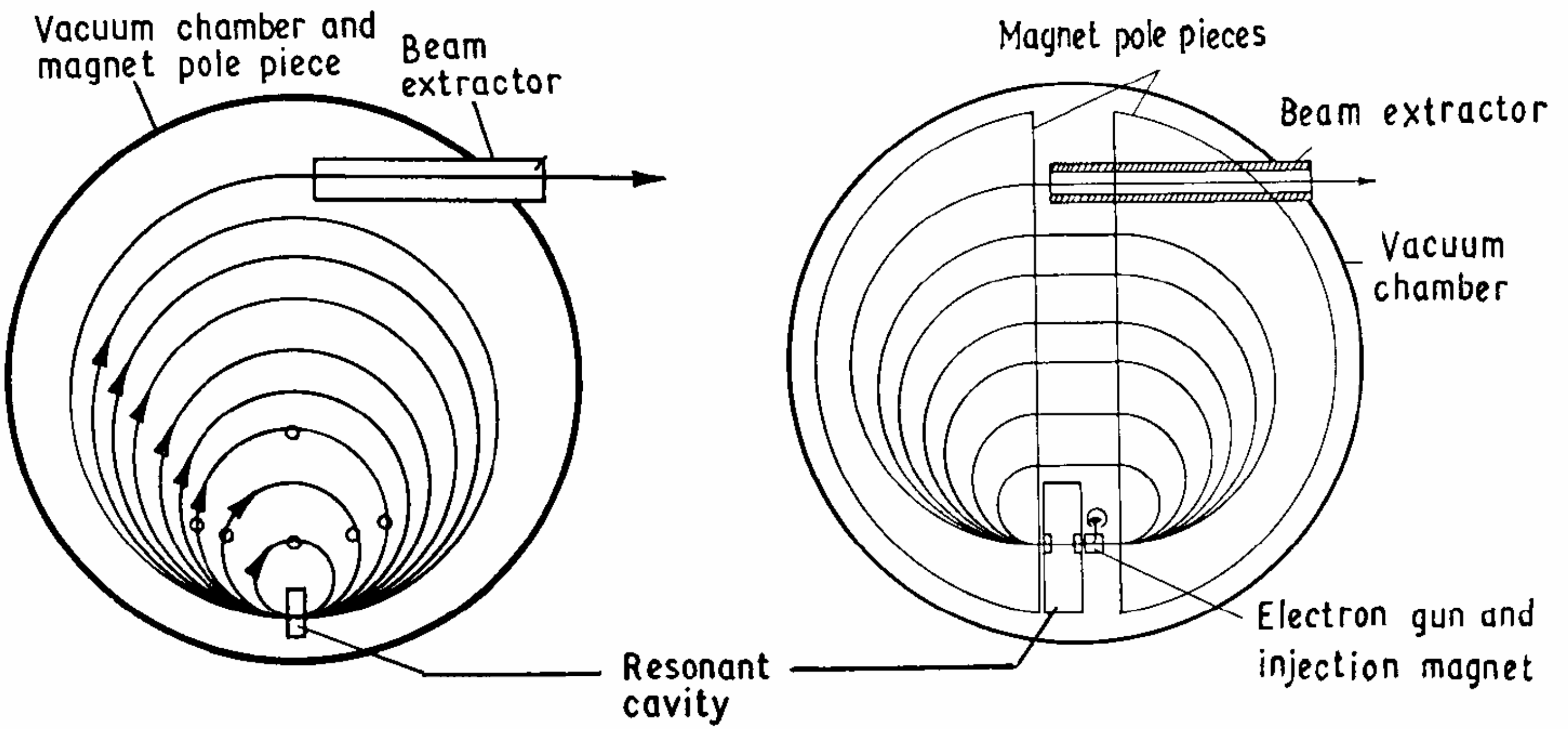
Microtron

- Acceleration in resonator – circular orbit with magnetic field; combination of linear accelerator and cyclotron



- Correlation between growth of radius and period