



Physics 417/517

Introduction to Particle Accelerator Physics

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Methods of Acceleration

- Acceleration by Static Electric Fields (DC) Acceleration
 - Cockcroft-Walton
 - van de Graaf Accelerators
 - Limited by voltage breakdowns to potentials of under a million volts in 1930, and presently to potentials of tens of millions of volts (in modern van de Graaf accelerators). Not enough to do nuclear physics at the time.
- Radio Frequency (RF) Acceleration
 - Main means to accelerate in most present day accelerators because one can get to 10-100 MV in a meter these days. Reason: alternating fields don't cause breakdown (if you are careful!) until much higher field levels than DC.
 - Ideas started with Ising and Wideröe

Cockcroft-Walton



Proton Source at Fermilab, Beam Energy 750 keV

van de Graaf Accelerator



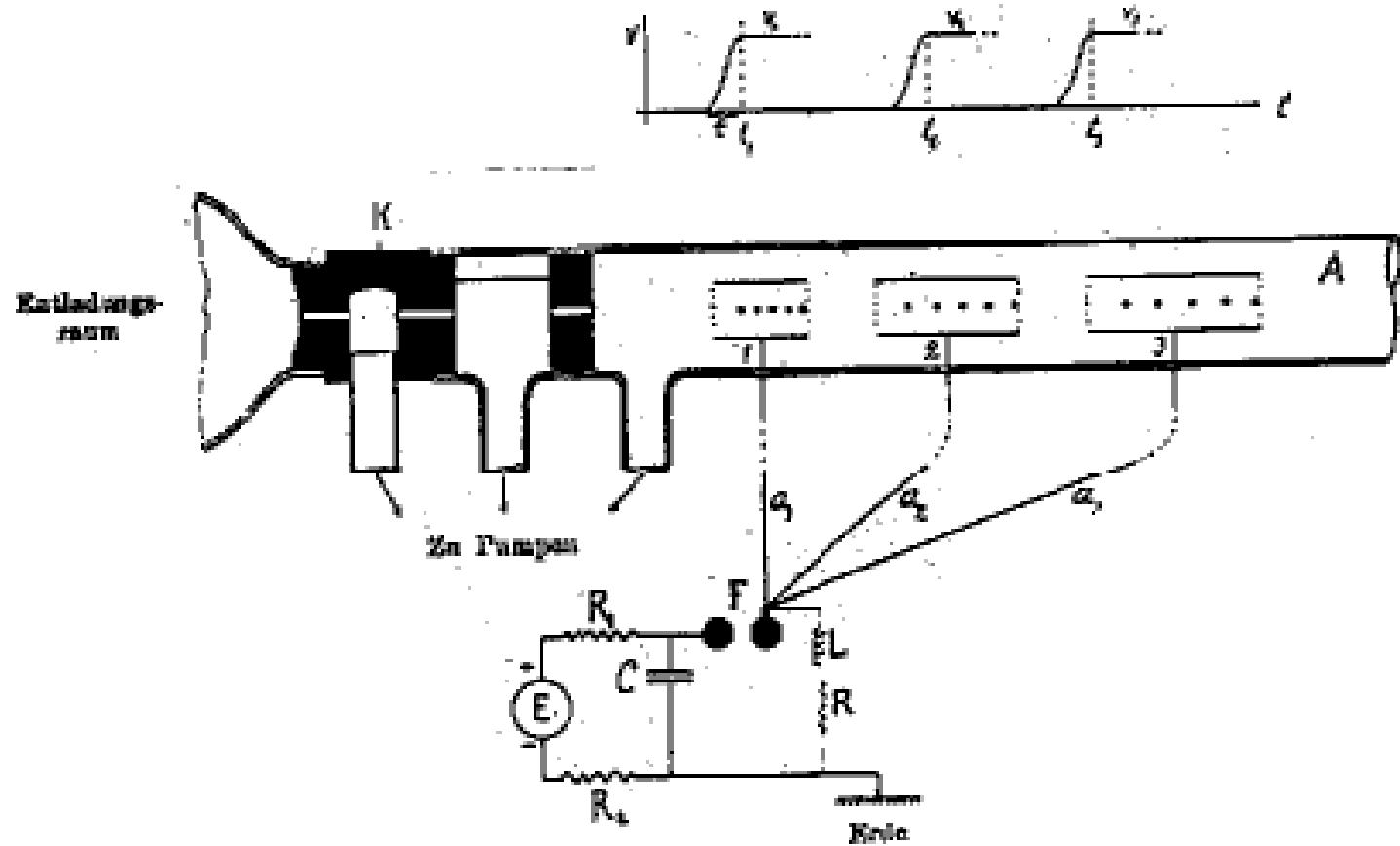
Generator



Brookhaven
Tandem
van de Graaf
~ 15 MV

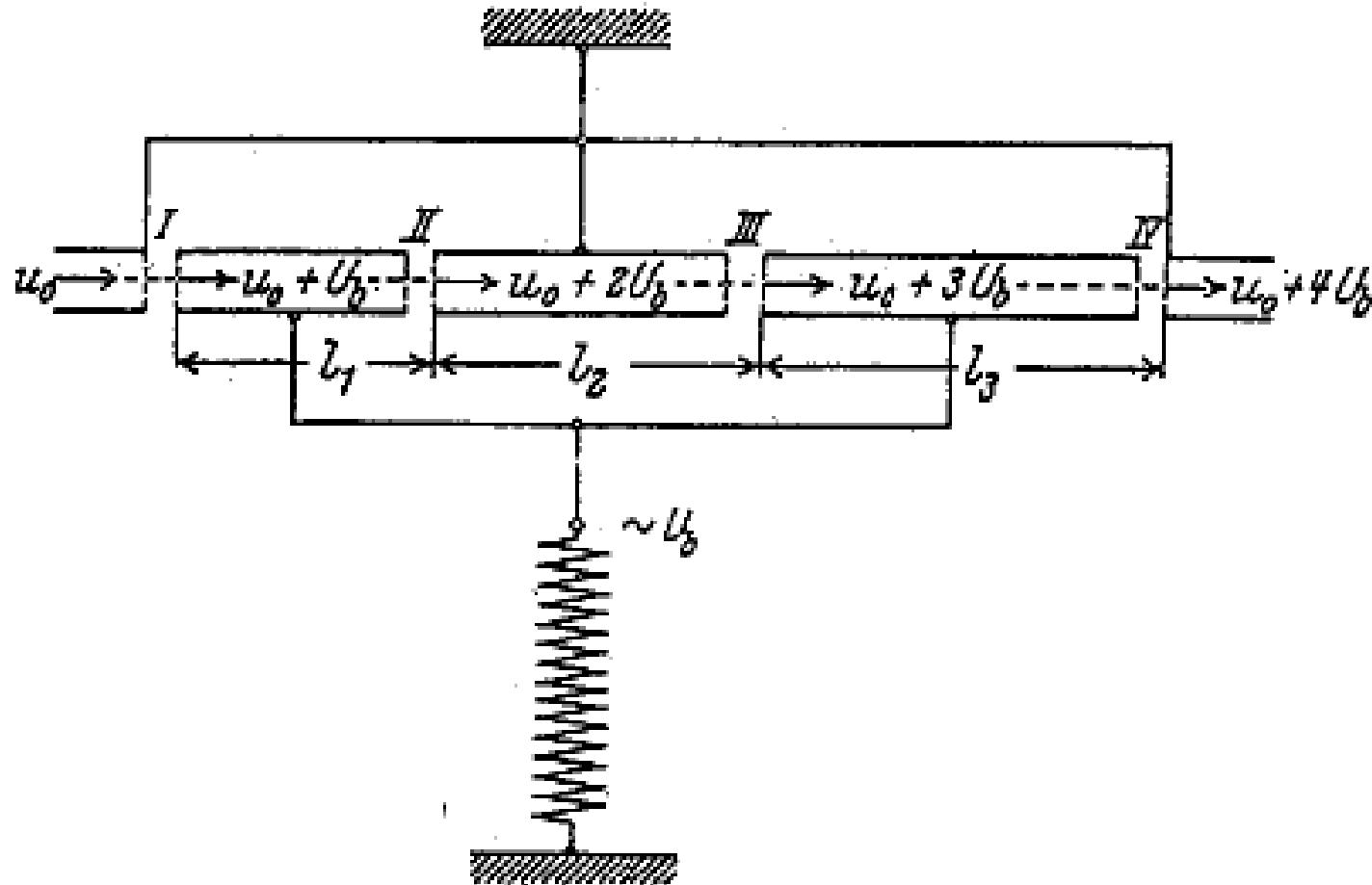
Tandem trick multiplies
the output energy

Ising's Linac Idea



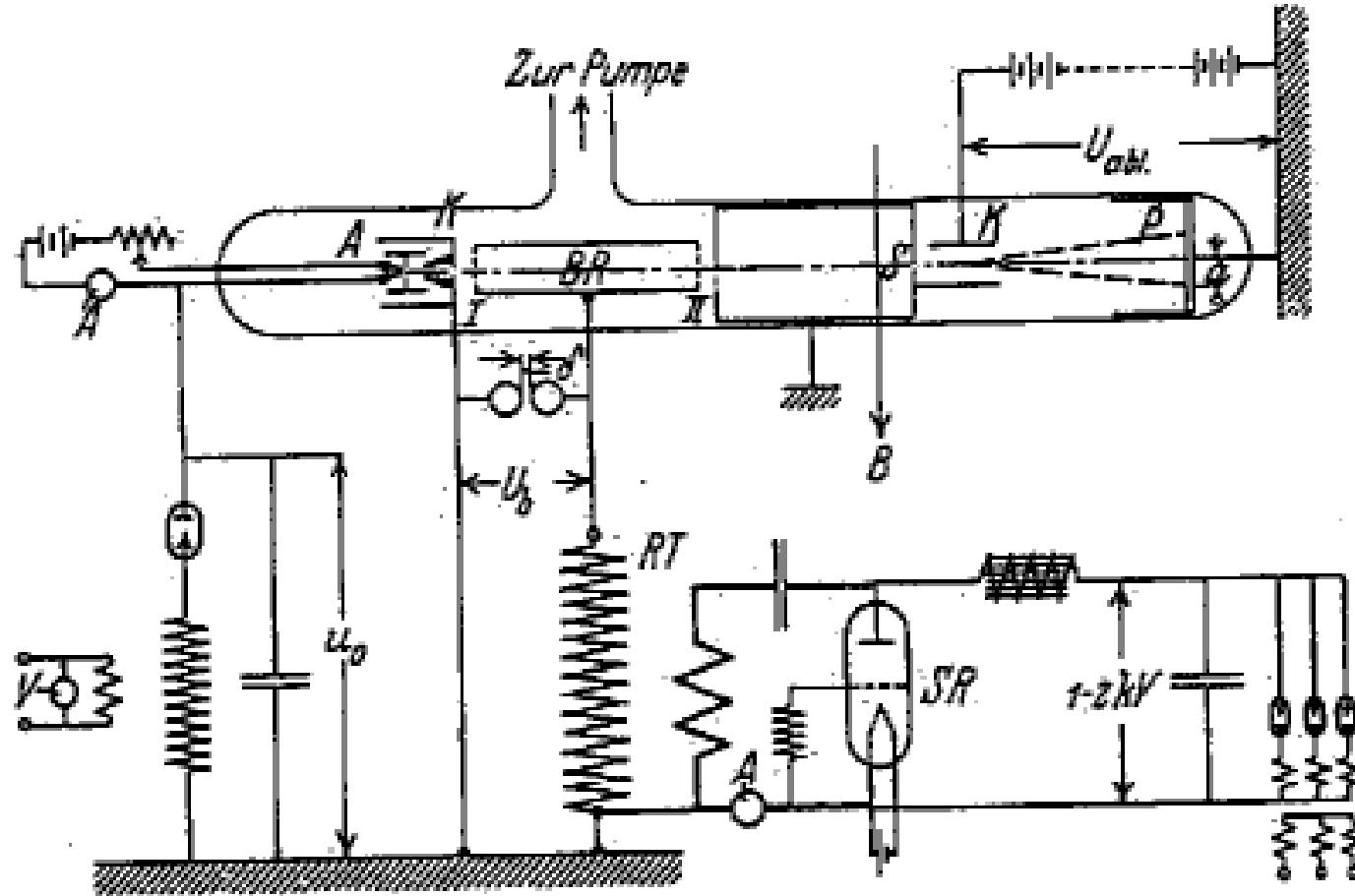
Prinzip einer Methode zur Herstellung von Kanalstrahlen hoher Voltzahl' (in German), Arkiv för matematik o. fysik, 18, Nr. 30, 1-4 (1924).

Drift Tube Linac Proposal



Idea Shown in Wideröe Thesis

Wideröe Thesis Experiment



Über ein neues Prinzip zur Herstellung hoher Spannungen, *Archiv für Elektrotechnik* **21**, 387 (1928)
(On a new principle for the production of higher voltages)

Sloan-Lawrence Heavy Ion Linac

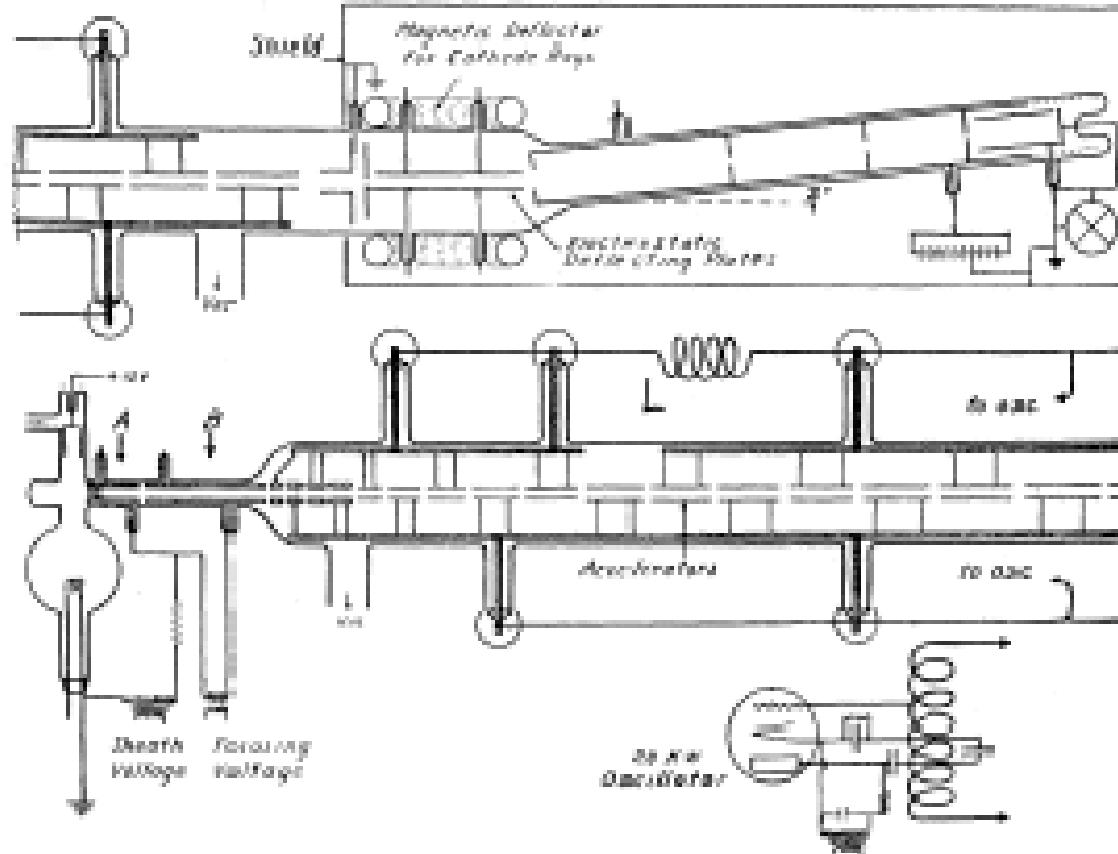


Fig. 1. Diagram of apparatus.

The Production of Heavy High Speed Ions without the Use of High Voltages
David H. Sloan and Ernest O. Lawrence Phys. Rev. **38**, 2021 (1931)

Alvarez Drift Tube Linac



- The first large proton drift tube linac built by Luis Alvarez and Panofsky after WW II
 - . (1945-1955) Alvarez Proton Linac

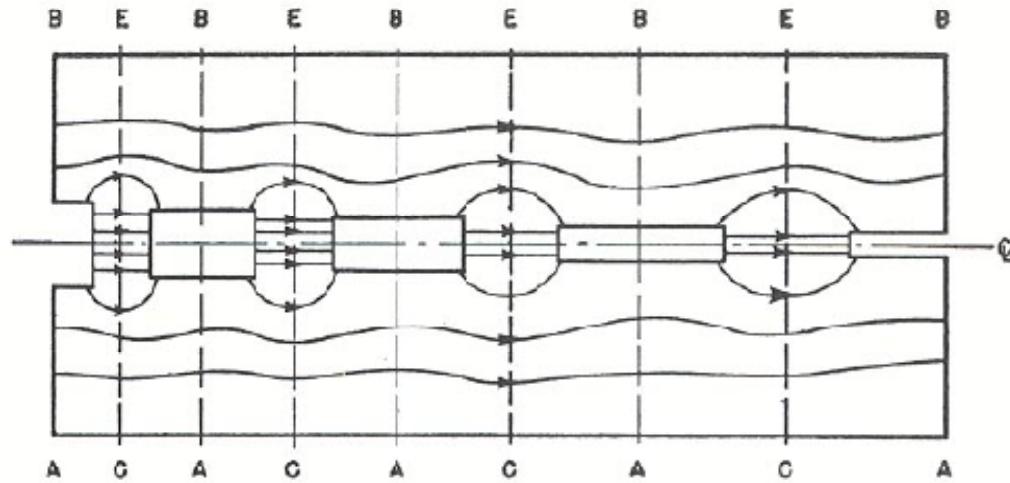


FIG. 2. Linear accelerator produced by introducing drift tubes into cavity excited as in Fig. 1. Division into unit cells.

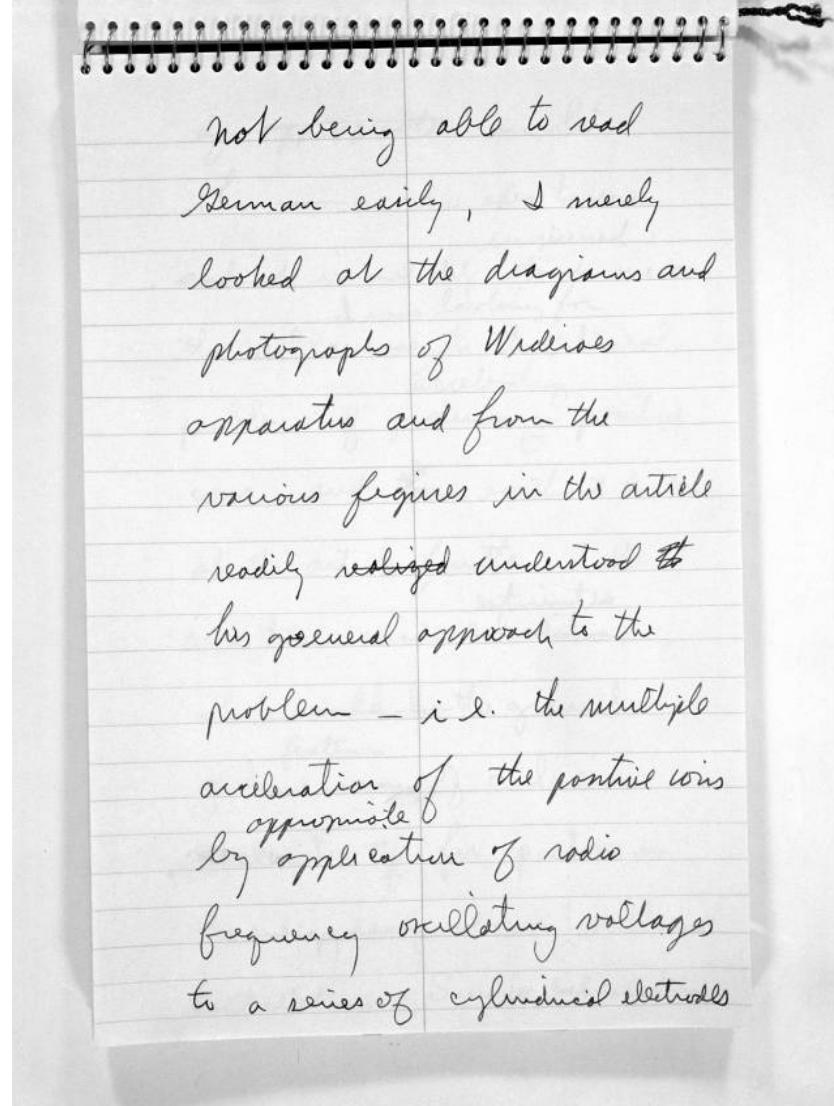
Alvarez, Bradner, Frank, Gordon, Gow, Marshal, F. Oppenheimer, Panofsky, Richman, and Woodyard, Rev. Sci. Instrum., **26**, 111-133, (1955)

Earnest Orlando Lawrence





Germ of Idea*



*Stated in
E. O. Lawrence
Nobel Lecture



Thomas Jefferson National Accelerator Facility

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Lawrence's Question



- Can you re-use “the same” accelerating gap many times?

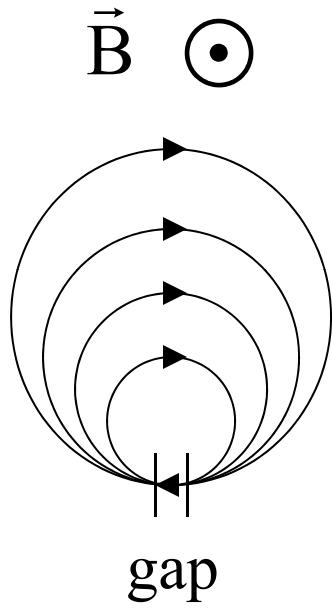
$$\vec{F} = m\vec{a} = q\vec{v} \times \vec{B}$$

$$\frac{d^2x}{dt^2} = \frac{qB}{m} v_y \rightarrow \frac{d^2v_x}{dt^2} + \Omega_c^2 v_x = 0$$

$$\frac{d^2y}{dt^2} = -\frac{qB}{m} v_x \rightarrow \frac{d^2v_y}{dt^2} + \Omega_c^2 v_y = 0$$

$$\frac{d}{dt} (v_x^2 + v_y^2) = \frac{qB}{m} (v_x v_y - v_y v_x) = 0$$

$v_0 = \sqrt{v_x^2(t) + v_y^2(t)}$ is a constant of the motion



Cyclotron Frequency



$$v_x(t) = v_0 \cos(\Omega_c t + \delta); v_y(t) = -v_0 \sin(\Omega_c t + \delta)$$

$$x(t) = x_0 + \frac{v_0}{\Omega_c} \sin(\Omega_c t + \delta); y(t) = y_0 + \frac{v_0}{\Omega_c} \cos(\Omega_c t + \delta)$$

The radius of the oscillation $r = v_0/\Omega_c$ is proportional to the velocity after the gap. Therefore, the particle takes the same amount of time to come around to the gap, independent of the actual particle energy!!!! (only in the non-relativistic approximation). Establish a resonance (equality!) between RF frequency and particle transverse oscillation frequency, also known as the Cyclotron Frequency

$$f_{rf} = f_c = \Omega_c / 2\pi = \frac{qB}{2\pi m}$$