Outline

1. Introduction
2. Electron sources
3. Ion sources
4. Final remarks
1 Introduction
2 Electron sources
3 Ion sources
4 Final remarks
What provides this lecture?

- some basic principles of particle production
- some examples of particle sources
- only a limited number of formulas and values, because this could be easily found in any text book
Introduction

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What can this lecture not provide?
- the complete theory of particle production
- the complete overview of all particle sources (e.g. radioactive ion sources, anti-proton sources, positron sources are not included)
- in-depth explanations
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- for more informations see the books listed in the bibliography
Why we need to speak about particle sources?

- One cannot start the acceleration from ordinary matter.
  ⇒ It has to be “charged” and a primary beam has to be “shaped”.

- It is important to understand the limitations of the source:
  (Beam intensity, emittance, charge state, beam structure, reliability and lifetime).

- Accelerator people tend to ”forget“ them and try to shift their problems towards the source.

- A basic knowledge of the source can help during the operation and is essential for designing an accelerator.

- It is always good to know where the source is and who the specialists are.
1 Introduction

2 Electron sources
   • Basic principles
   • Electron guns

3 Ion sources

4 Final remarks
the **perveance** $P = \frac{I}{U^{3/2}}$ is a gun parameter, that is based on the space charge limit of the beam and depends only on the electrode geometry and not on the electron emitter ($I$ — beam current, $U$ — voltage between anode and cathode)

the **brightness** $B \propto \frac{I}{\varepsilon_x \varepsilon_y}$ is a value to describe the quality of the beam ($I$ — peak current, $\varepsilon$ — transverse normalised emittance)
there are different mechanisms to "produce" the electrons
⇒ thermionic emission, photoemission, field emission
there exist a big variety of cathodes in terms of the shape and in terms of material
the electric field can be DC or RF
⇒ fast acceleration needed to overcome space charge, RF fields allow a higher voltage to get a more brilliant beam
the focusing can be pure electrostatic or including magnetic fields
unpolarized or polarized beams
High voltage DC gun with thermionic cathode

- simple structure, robust, long lifetime
- grid in front of the cathode to switch the current
- good stability (pulse to pulse and long term)
- limited brilliance ("slow" acceleration)
- main mode of failure: external (e.g. power supplies)
RF gun with photocathode

- The concept of the photo injector was first proposed and tested in the mid-1980s by J.S. Fraser and R.L. Sheffield.
- A photocathode is enclosed in a 2½ cell RF cavity.
- The beam pulse structure is defined by the laser pulse.
- The pulse to pulse stability depends on the laser (limited).
- High brilliance (due to the high RF field).
- Short lifetime of the cathode (weeks).
- Very good vacuum needed (problem of recoil ions).
1 Introduction

2 Electron sources

3 Ion sources
   - Basic principles
   - The Duoplasmatron
   - The Electron Cyclotron Resonance Ion Source (ECRIS)
   - The Electron Beam Ion Source (EBIS)
   - The RF driven H\textsuperscript{−} source

4 Final remarks
The ion production

Basic differential equation concerning the ion production process (simplified)

\[
\frac{dn_i}{dt} = n_{i-1}\sigma_{i-1}j_e - n_i\sigma_{i,i+1}j_e - \frac{n_i}{\tau_c(i)}
\]

- terms of ion production and ion losses
- the ion confinement time \(\tau_c(i)\) influences the charge state that could be reached but also the ion current that can be extracted
- a complete model needs to include also the single particle transport (diffusion), the macroscopic behaviour (waves, MHD), the plasma–wall interaction, the energy balance (electron heating)
Processes increasing the charge state $q^{n+} \rightarrow q^{(n+i)+}$
- ionisation
  - single ionisation
  - double ionisation
  - creating of higher charge states is a step-by-step process
- ionisation process has a energy threshold
  $\Rightarrow$ the production of higher charge states needs a higher electron energy
- charge exchange (for low $n$)

Processes decreasing the charge state $q^{n+} \rightarrow q^{(n-i)+}$
- recombination
  - radiative recombination
  - the cross sections are bigger for lower electron temperatures
  - dielectronic recombination (resonant process)
- charge exchange (for high $n$)
  - depending on the neutral particle density (rest gas)
  - cross sections are bigger for higher charge states
The H\(^-\) production

- **charge transfer**: the simplest method is the conversion of a primary proton beam in a converter target (e.g. a caesiated surface, caesium vapour or hydrogen gas)
- **surface effect**: protons from a plasma hitting the wall can pick up electrons, the walls are covered with low work function material (e.g. caesium)
- **volume effect**: H\(^-\) is created from vibrational excited hydrogen molecules through dissociative electron attachment

\[
H_2(\nu'') + e^- \rightarrow H^- + H
\]

- H\(^-\) ions are very sensitive to particle collisions
Source input and output

Particle input media

- gas
- liquids
- solids

N.B. These lists are not exhaustive.
Source input and output

**Particle input media**
- gas
- liquids
- solids

**Particle feeding methods**
- low vapour pressure agents
- volatile chemical compounds
- sputtering
- oven
- laser evaporation
- single charge ion source

_N.B. These lists are not exhaustive._
### Particle input media
- gas
- liquids
- solids

### Energy feeding
- electrical discharges (filament sustained)
- radio frequency (internal or external antenna)
- microwave
- laser
- electron beam

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Extraction
- system of several electrodes
- source body on high voltage
- beam extraction and shaping
- initial emittance creation

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The Duoplasmatron

developed 1956 by Manfred von Ardenne

- driven by an arc discharge sustained by a heated filament
- a strong magnetic field in the discharge region increases the plasma density
- hydrogen gas is used as input medium
- in the expansion cup the plasma density is reduced to decrease the beam divergence
- delivers short pulses with a very high intensity of mostly mono charged ions
The Electron Cyclotron Resonance Ion Source (ECRIS) developed 1965 by Richard Geller.

- The plasma is confined in a "magnetic bottle", the longitudinal field is created with solenoids, the radial field is created with a magnetic hexapole.
- The plasma is heated due to the resonance of the injected microwave with the electron cyclotron frequency $\omega_c = \frac{eB}{m_e}$.
- (Actual used frequencies 14.5 GHz, 18 GHz or 28 GHz)
- "Afterglow" mode of operation: pulsing the microwave power results in a peak current of the higher charge states after the end of the microwave pulse.
- Delivers high currents for medium charge states.
- No antennas or filaments in the ion production region $\Rightarrow$ high reliability.
The Electron Beam Ion Source (EBIS) developed 1965 by Evgeni D. Donets

- the longitudinal confinement is given by electrostatic fields, the radial confinement is given by the electron beam, which is compressed by a solenoidal field
- ionsation takes place inside the high energetic, high density electron beam
- delivers short pulses of high charge states
- the extraction process is controlled by the voltage level of the trap electrodes
- the total current depends on the trap charge capacity
- low emittance
- the life time and the reliability is mainly defined by the electron gun
The RF driven $H^-$ source

- RF driven ion sources were developed in the late 1940s, negative ion sources were developed according to requirements
- the $H^-$ is created in the volume process
- the RF power is coupled inductively into the plasma
- the plasma region separated by a magnetic filter into two regions of different electron temperature
- the plasma is confined by a magnetic cusp structure
- the ignition of the plasma is supported by an electron gun
- the co-extracted electrons are removed in an spectrometer
- delivers pulsed high currents of $H^-$
- caesium free and no antenna or filament in the plasma ⇒ high reliability
1 Introduction

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Final remarks

- particle sources are an essential part of the accelerator chain
- all particle sources have certain limitations that define their field of application, there is no universal source
- the reliability of the source contributes to the availability of a beam from the accelerator
- ion sources can create primary or secondary beams in a wide range of charge states and current
Sources at CERN

*Duoplasmatron*

*EBIS*

*Linac4*

*H^+ source*

*ECRIS*

*e^− gun*


