Study Meeting 1: Electron Guns

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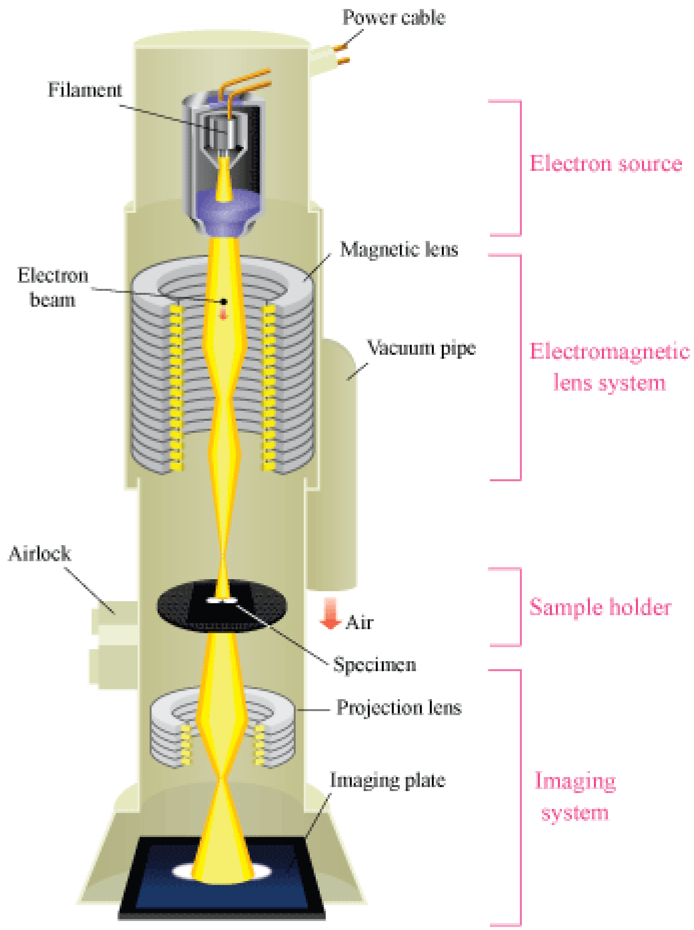
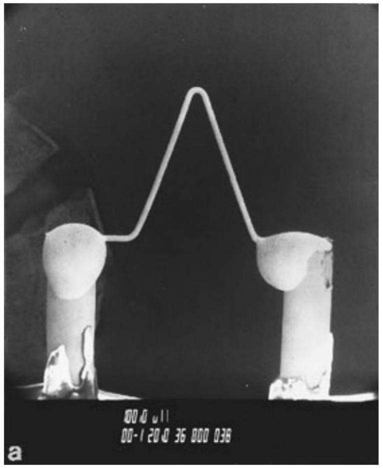
COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

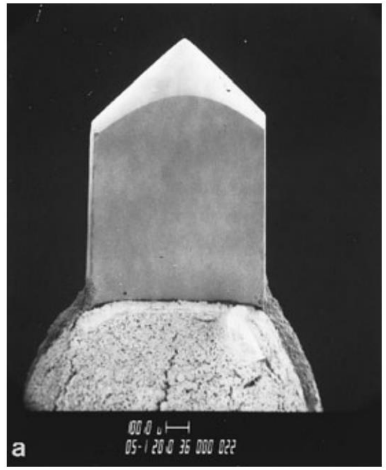


Power cable
Filament
Electron source
Magnetic lens
Electron
beam
Vacuum pipe
Electromagnetic
lens system
Airlock
Sample holder
Air
Specimen
Projection lens
Imaging plate
Imaging
system

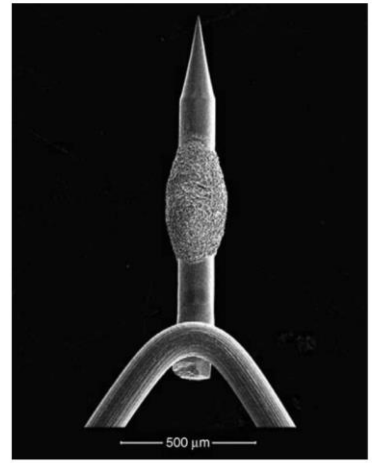
Four types of electron gun



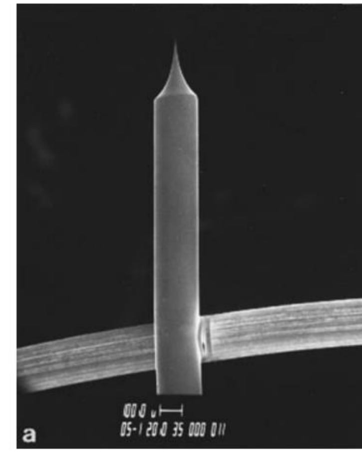
Tungsten



LaB_6



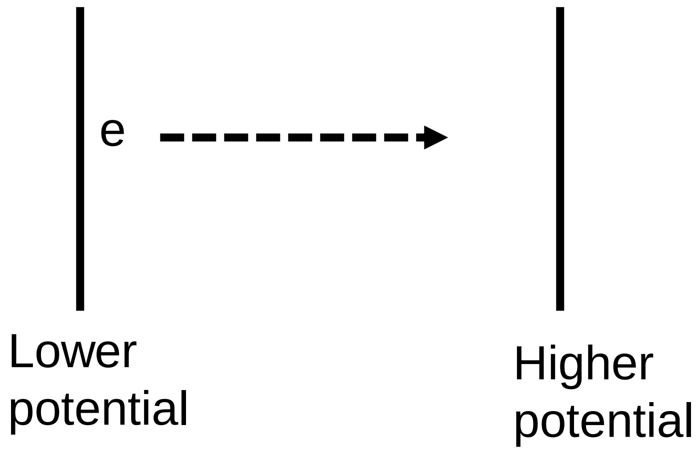
Schottky



Cold FEG

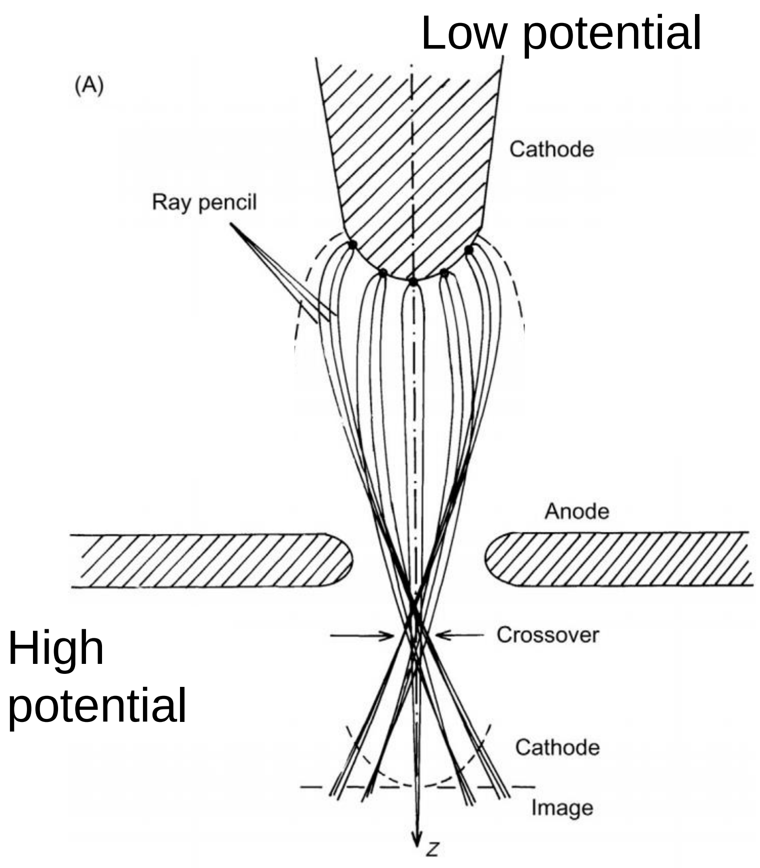
Design of a simple electron gun

- Some assumptions for biologists
  - Electrons move from lower potential to higher potential



  - We can make electrons come out of metal by heating it enough

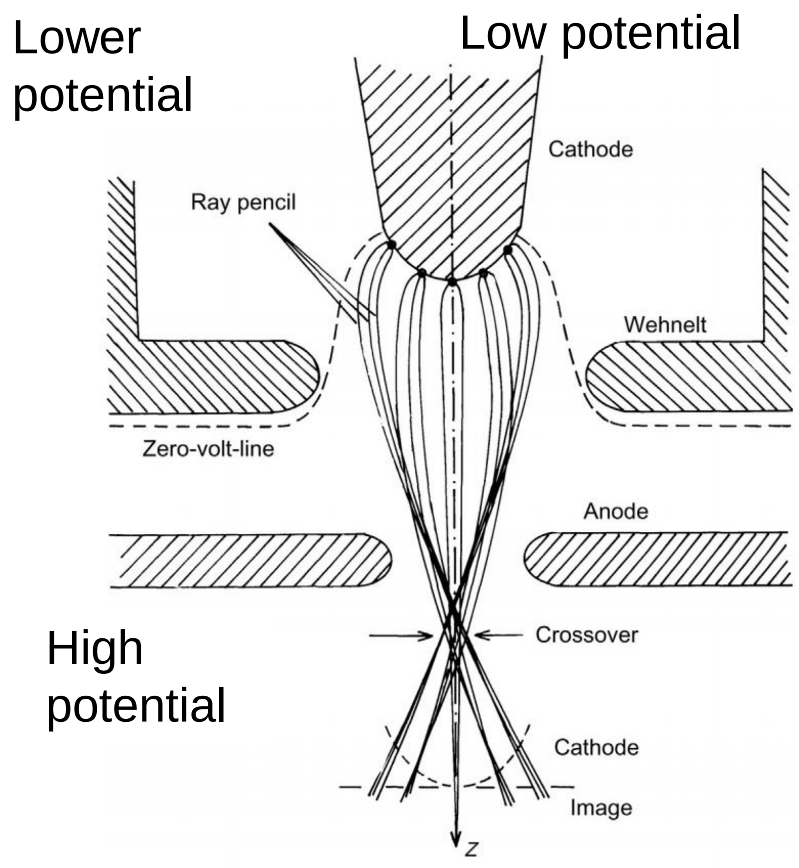
Design of a simple electron gun



- Cathode and extractor electrode
- Heating causes electrons to come out
- Not very efficient as heat of cathode is needed to change the electric current
- Wehnelt (in 1903) introduced a third electrode that is held a negative potential with respect to the cathode.

Hawkes (2018)
Fig. 43.1

Design of a simple electron gun



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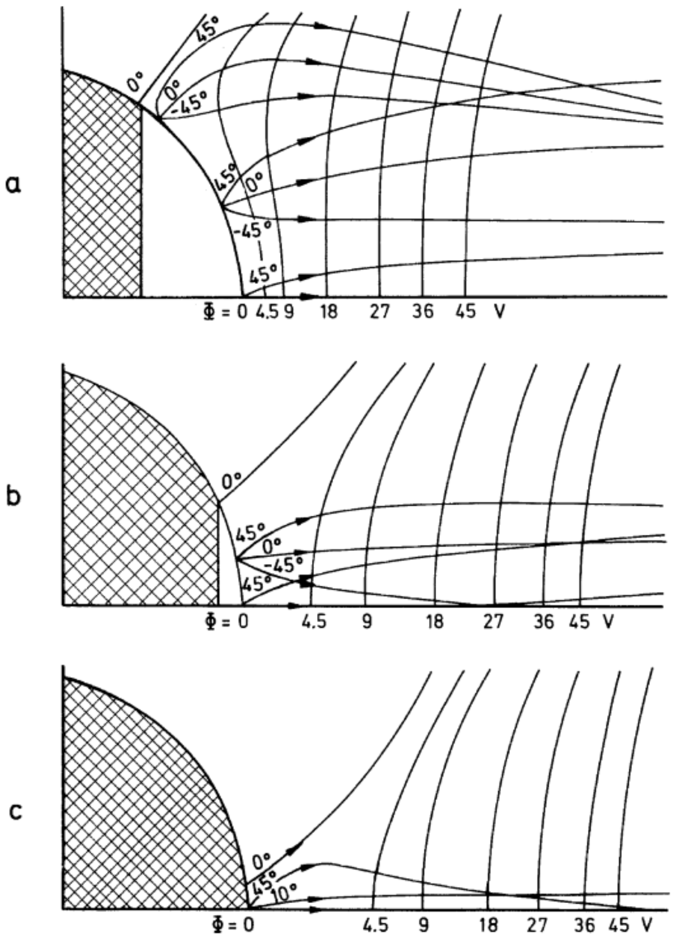
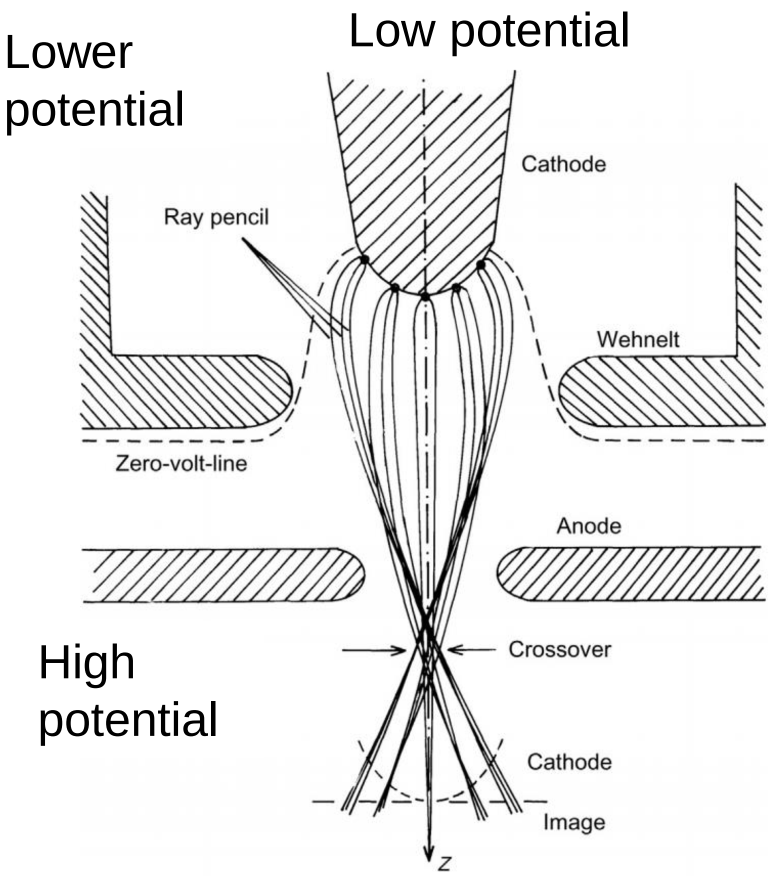
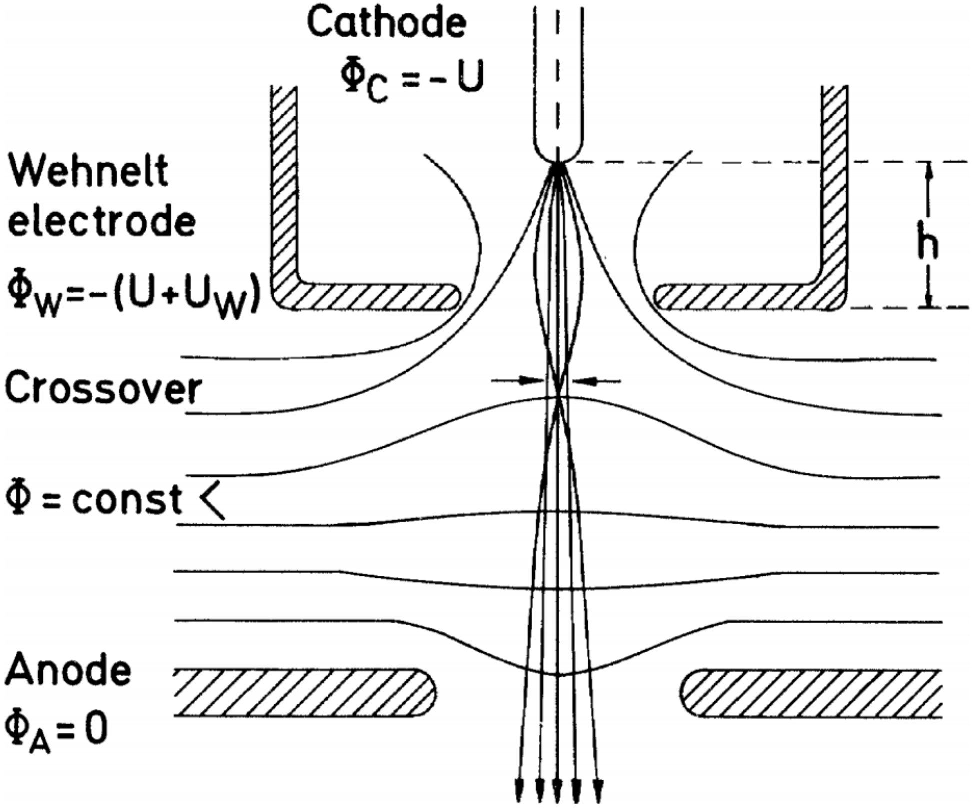
Hawkes (2018) Fig. 43.1

Wehnelt


a
b
c
Φ = 0 4.5 9 18 27 36 45 V
Φ = 0 4.5 9 18 27 36 45 V
Φ = 0 4.5 9 18 27 36 45 V


Lower potential
Low potential
High potential
Cathode
Ray pencil
Wehnelt
Zero-volt-line
Anode
Crossover
Cathode
Image
z

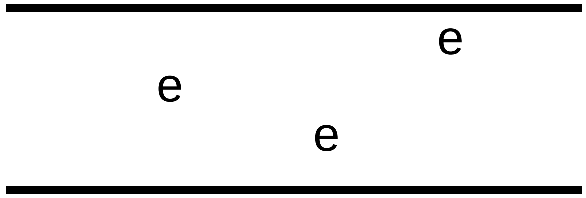
Basic design of an EM gun



Reimer & Kohl (2008)
p. 18

What's happening in more detail

- Things have electrons in them
- Heating the material causes electrons to get some thermal energy and leave



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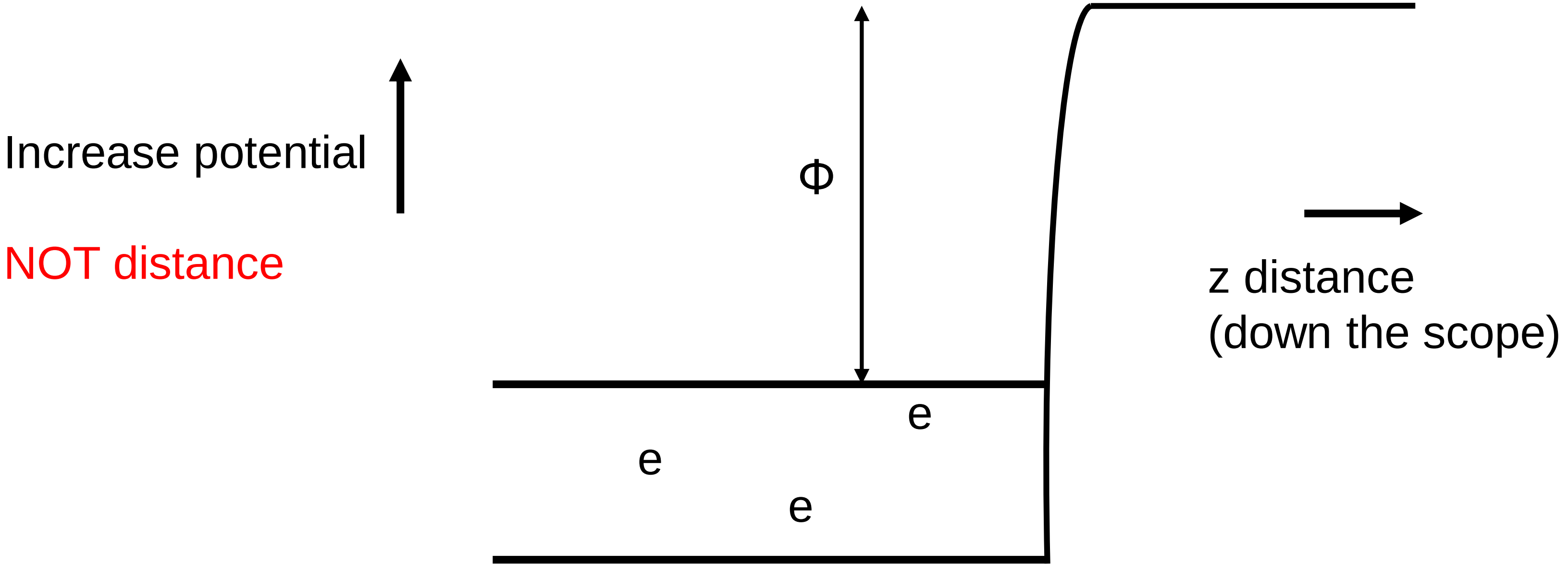

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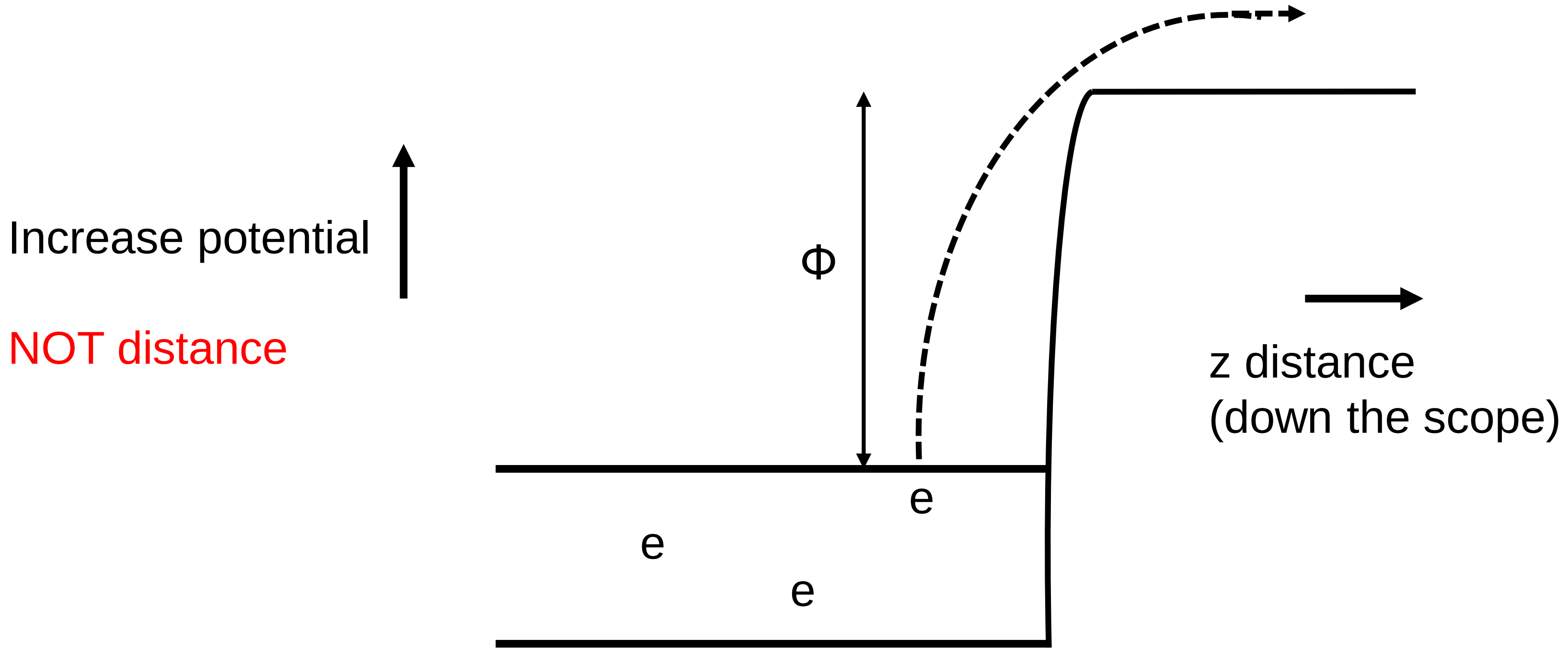
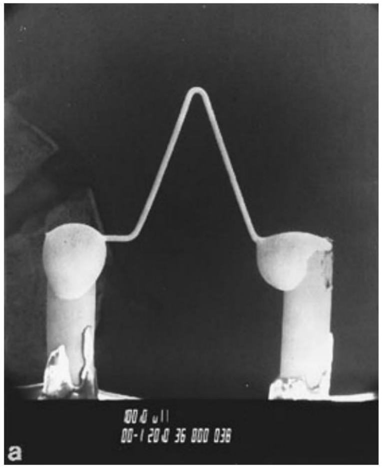
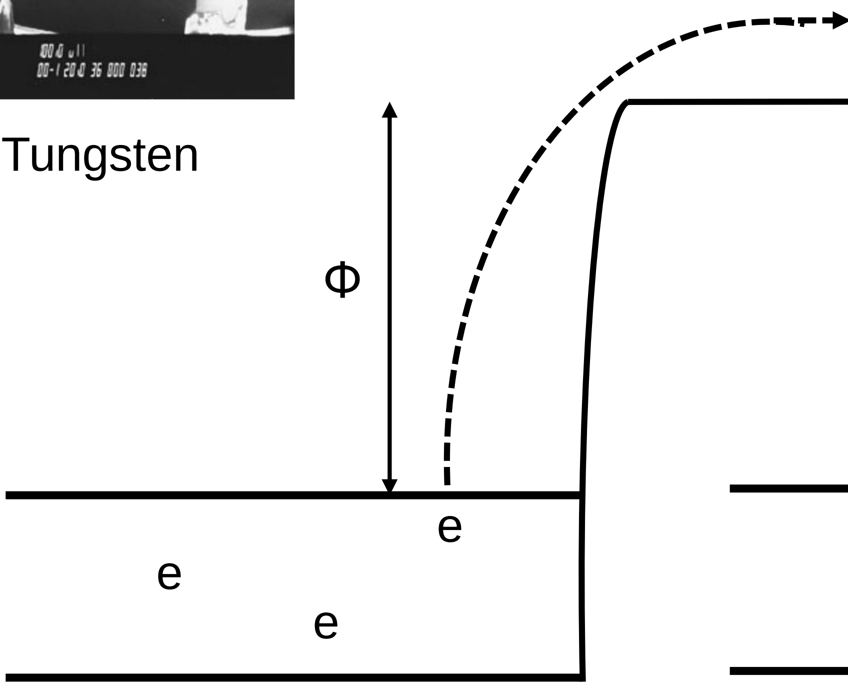


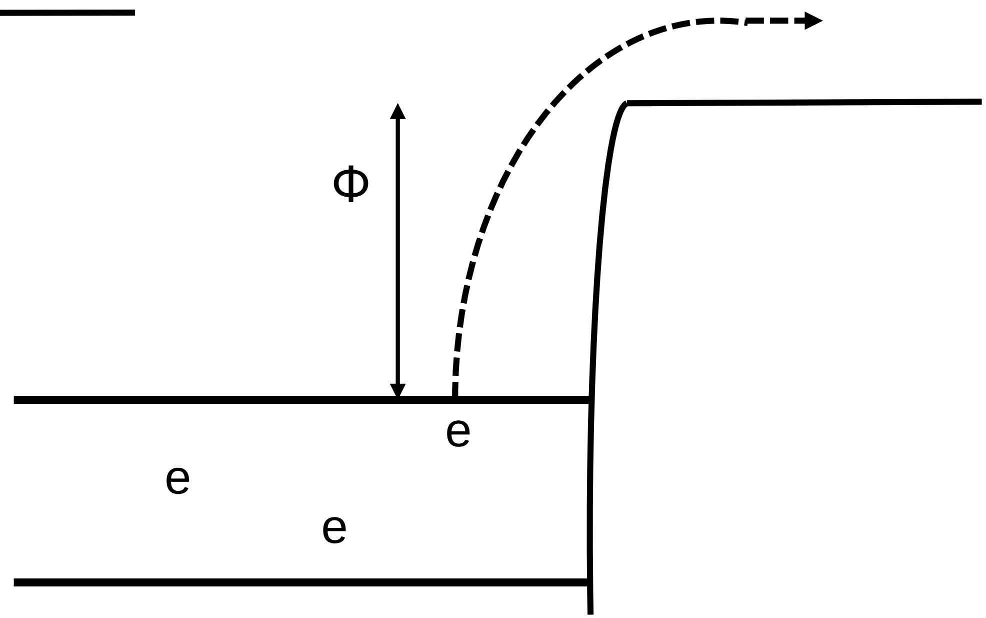
Thermionic guns



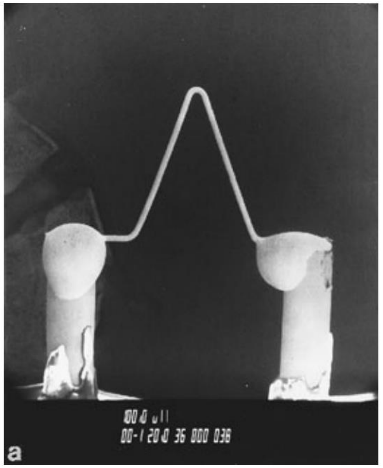
Tungsten

LaB_6

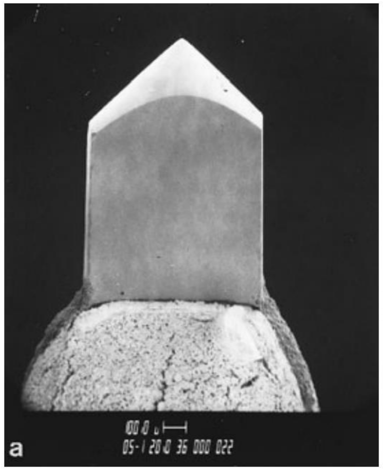




Short comparison



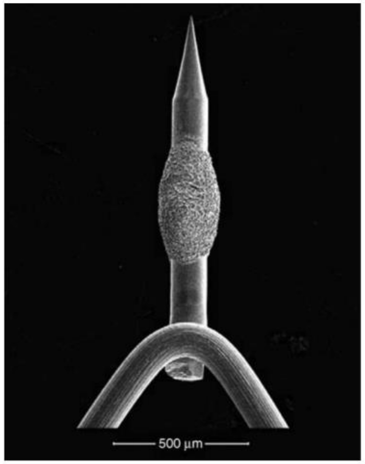
Tungsten



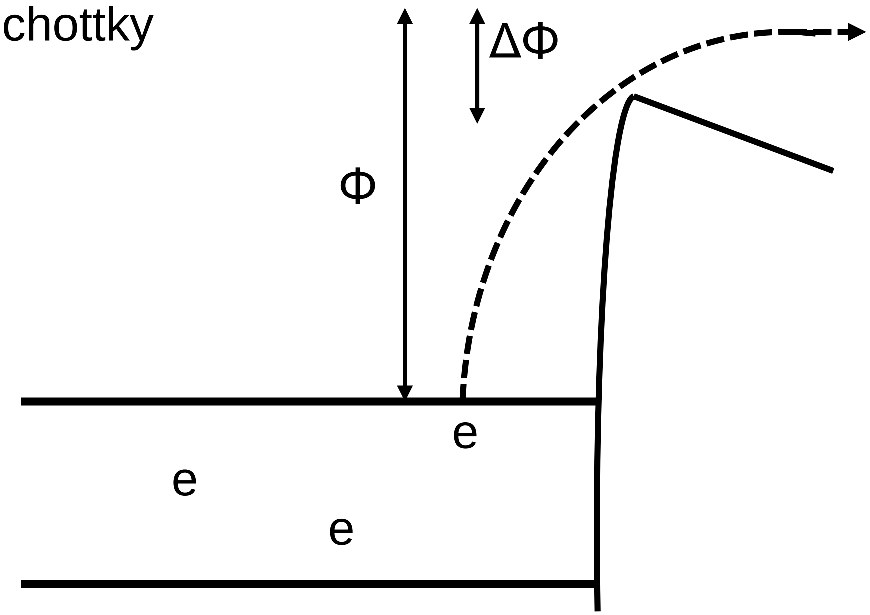
LaB_6

	Units	Tungsten	LaB_6
Temperature	K	2500-3000	1400-2000
Work function (Φ)		4.5 eV	2.7 eV
Vacuum	Pa	10^{-2}	10^{-4}
Stability	%/hr	<1	<1

Schottky guns

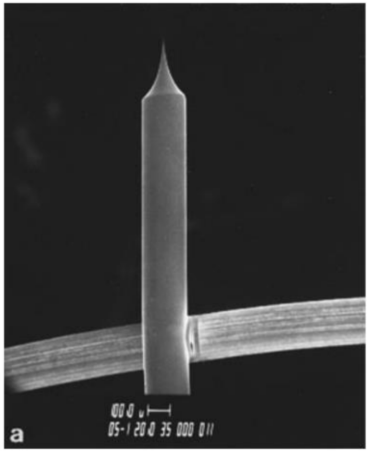


Schottky

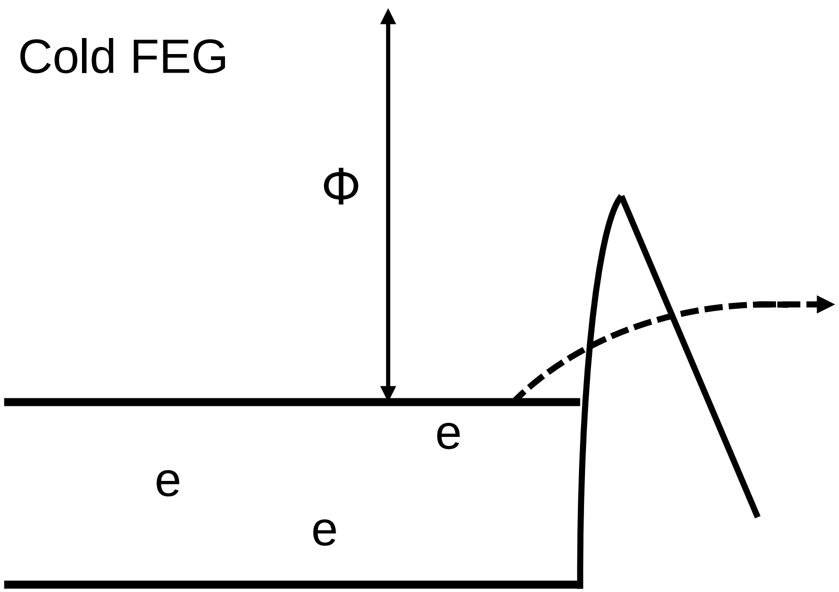


- A strong electric field can lower the work function by ΔΦ
- Now the electron has a smaller barrier to overcome
- Heating is still needed to provide ?most? of the energy
- *Field assisted thermionic guns*

Field Emission guns

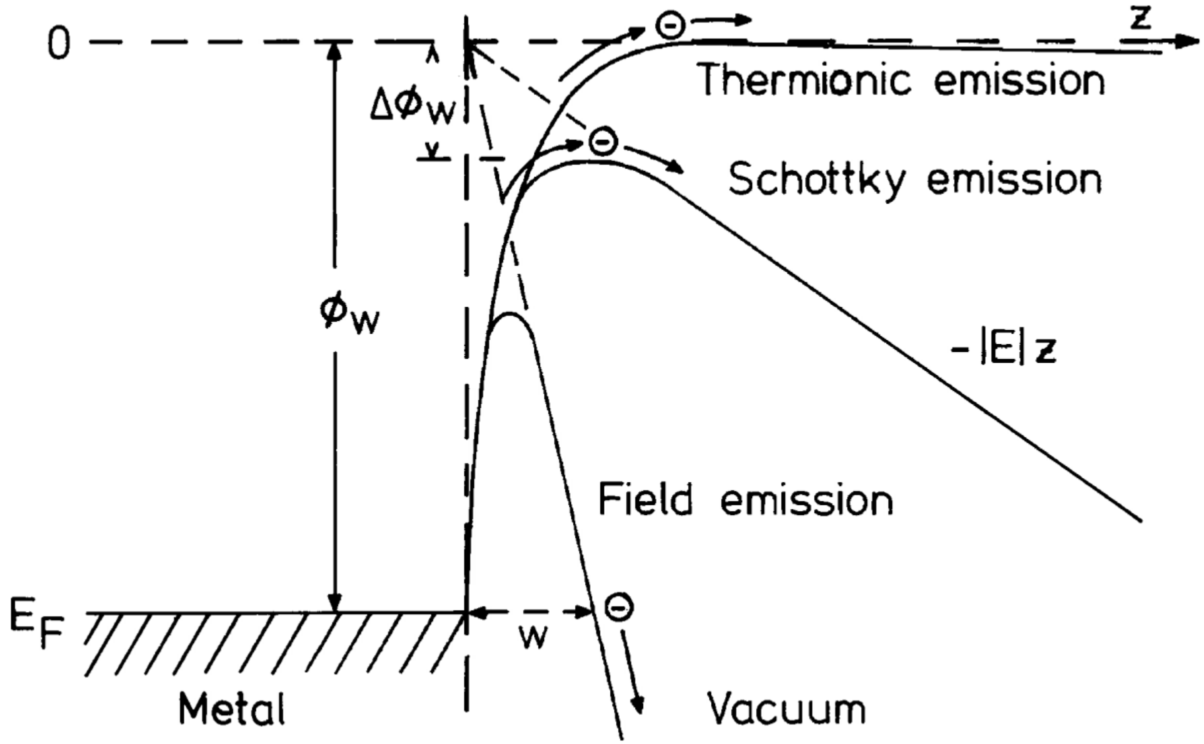


Cold FEG



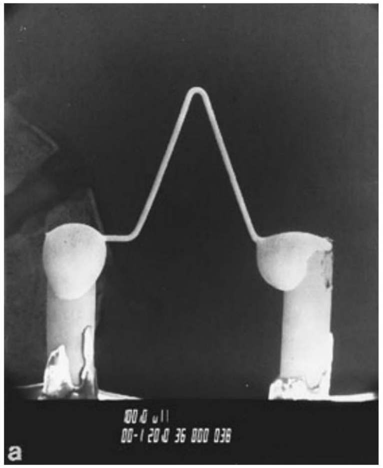
- A very strong electric field causes a flattening of the barrier and electrons can just tunnel through

Different ways to get electrons

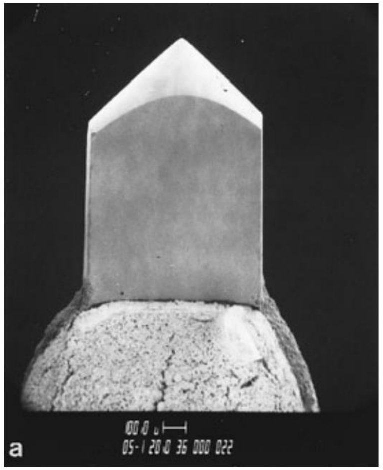


Reimer & Kohl (2008)
Fig. 4.1

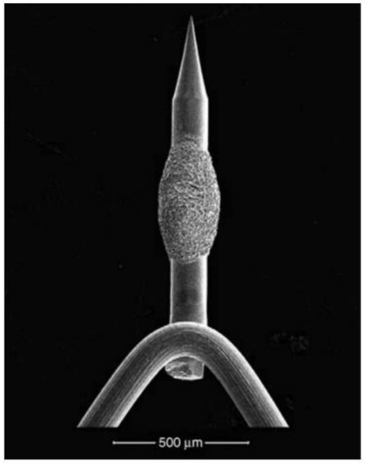
Short comparison



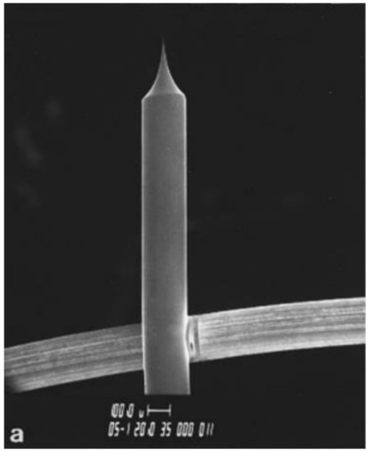
Tungsten



LaB_6



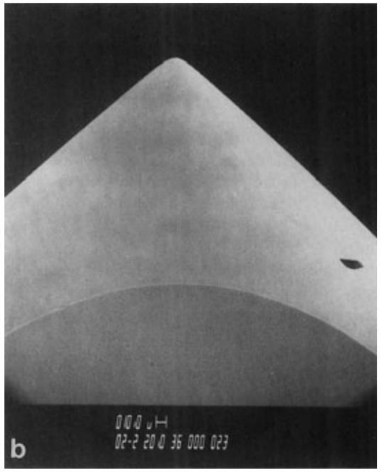
Schottky



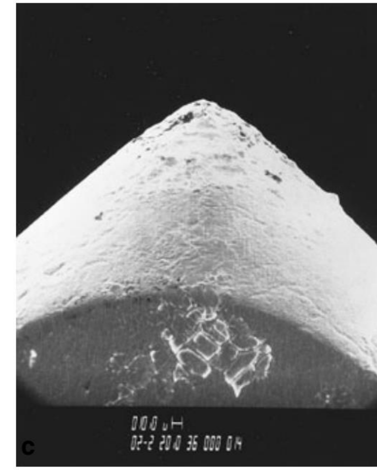
Cold FEG

	Units	**Tungsten**	**LaB_6**	**Schottky**	**Cold FEG**
Temperature	K	2500-3000	1400-2000	1800	300 or 1500
Work function (Φ)		4.5 eV	2.7 eV	2.7 eV	4.5 eV
Vacuum	Pa	10^{-2}	10^{-4}	10^{-6}	10^{-9}
Stability	%/hr	<1	<1	<1	5

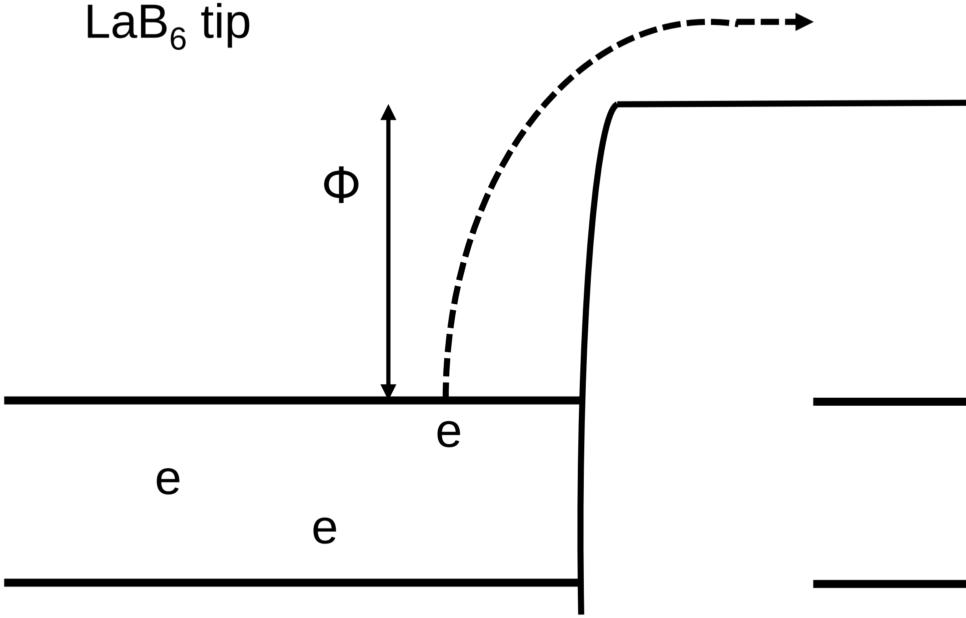
Thermionic guns

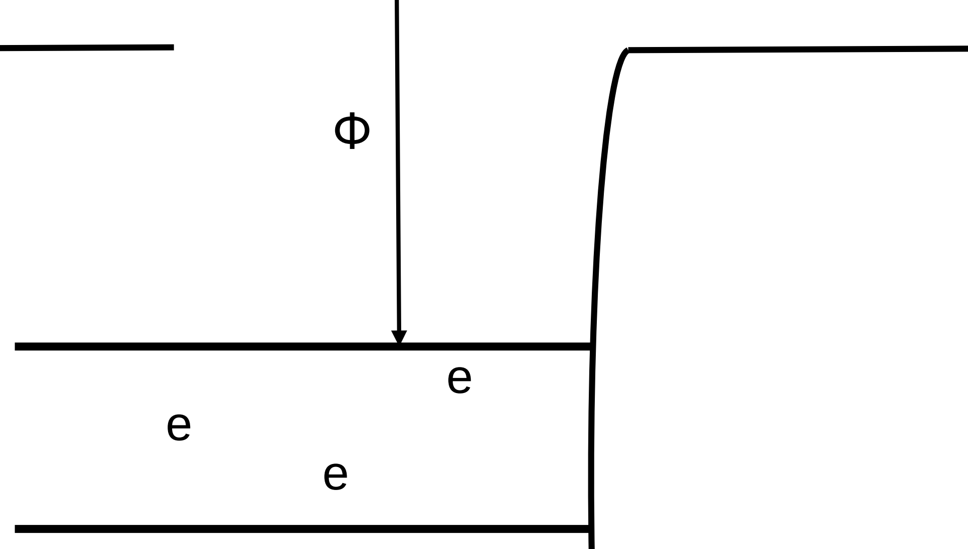


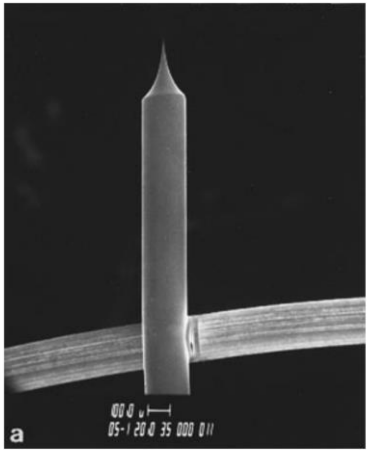
LaB_6 tip



‘poisoned’ LaB_6







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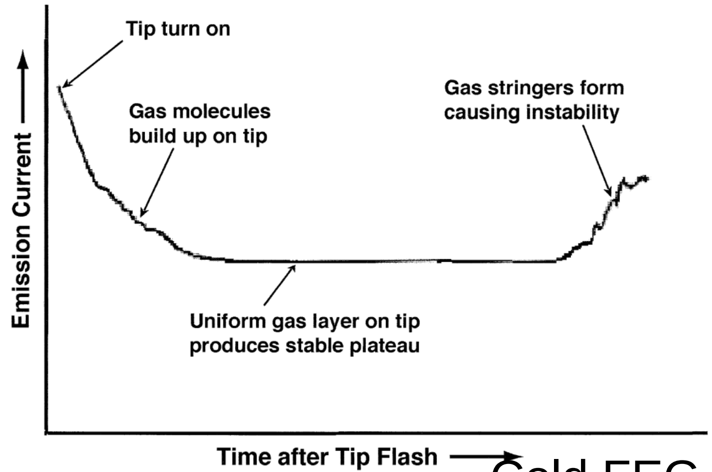

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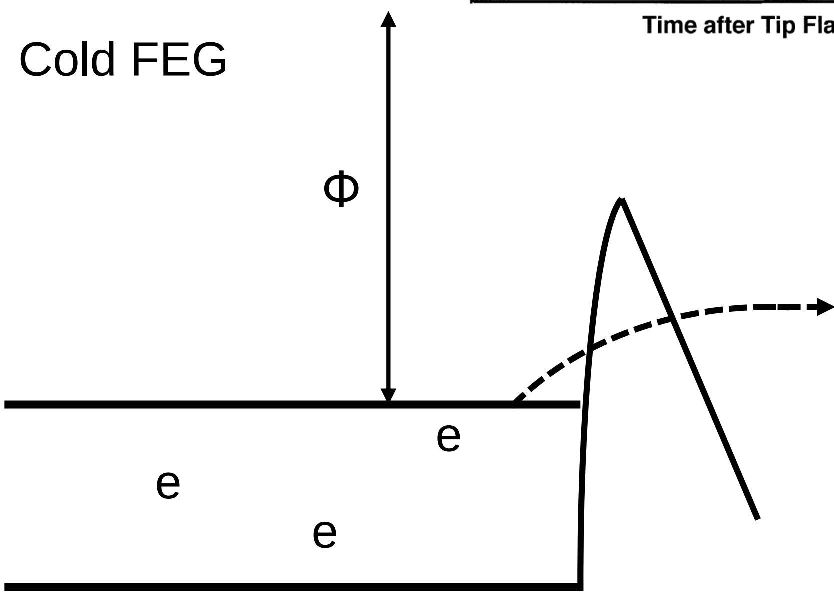
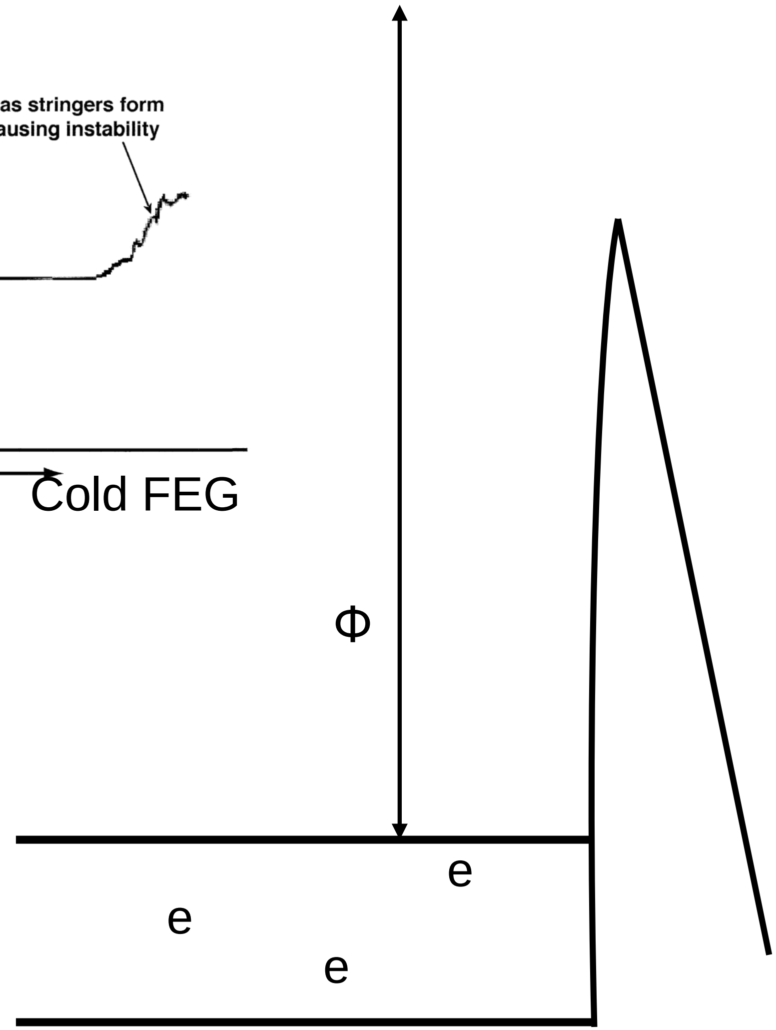
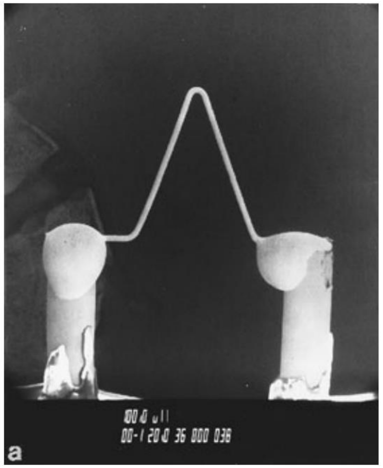




Short comparison



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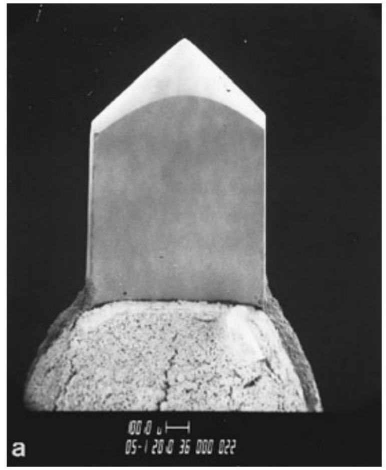

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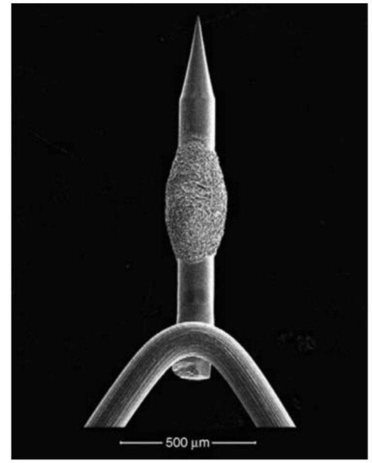
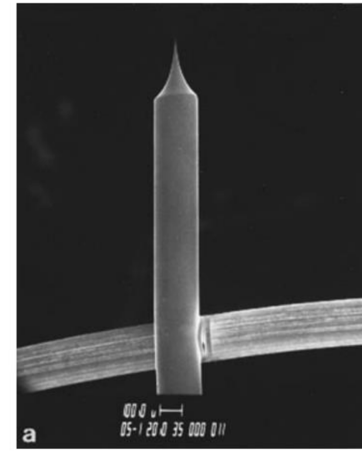


Schottky

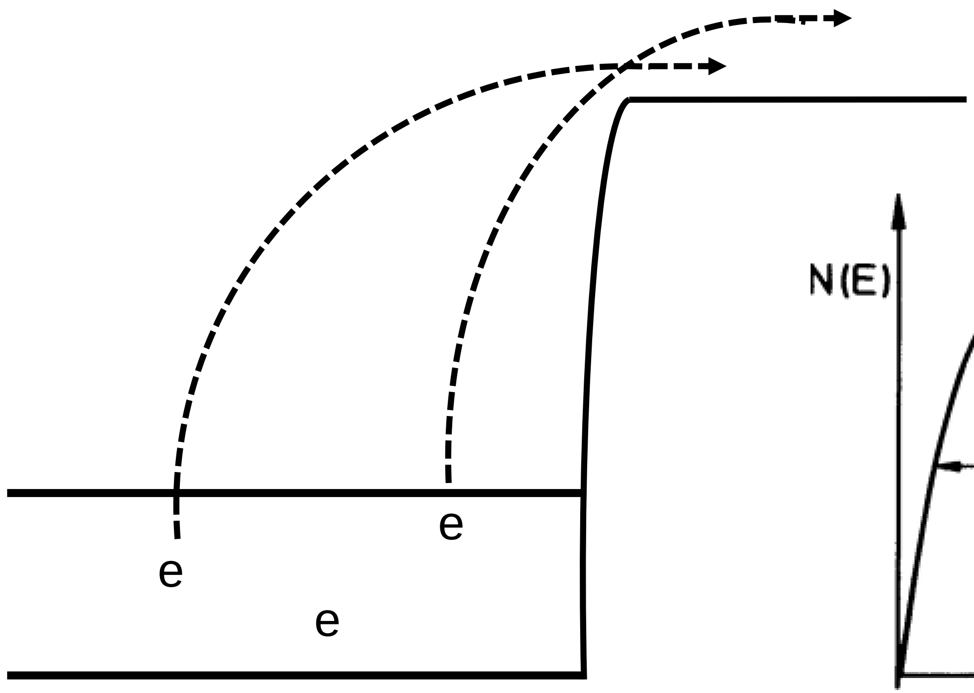


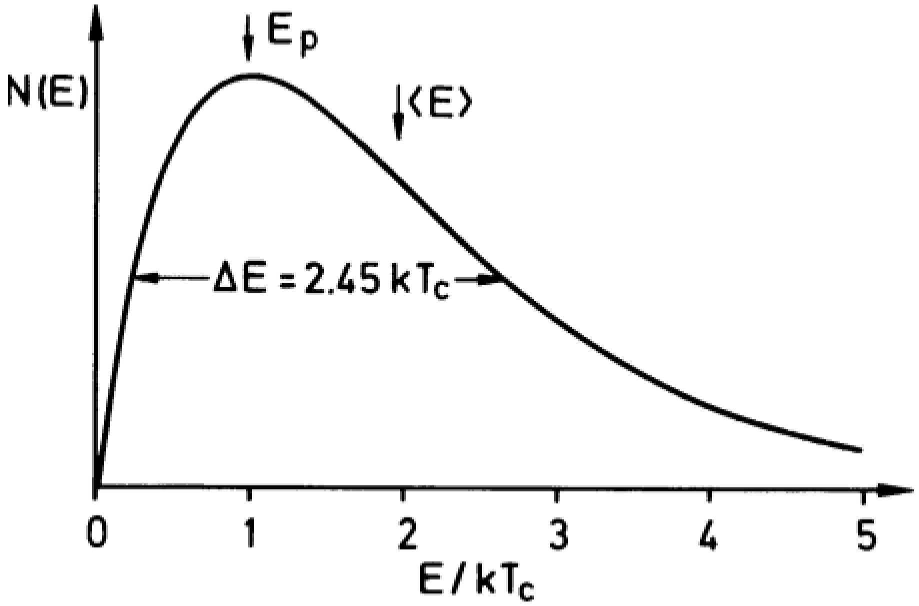
Cold FEG

	Units	Tungsten	LaB_6	Schottky	Cold FEG
Temperature	K	2500-3000	1400-2000	1800	300 or 1500
Work function (Φ)		4.5 eV	2.7 eV	2.7 eV	4.5 eV
Vacuum	Pa	10^{-2}	10^{-4}	10^{-6}	10^{-9}
Stability	%/hr	<1	<1	<1	5
Energy spread	eV	3	1.5	0.7	0.3

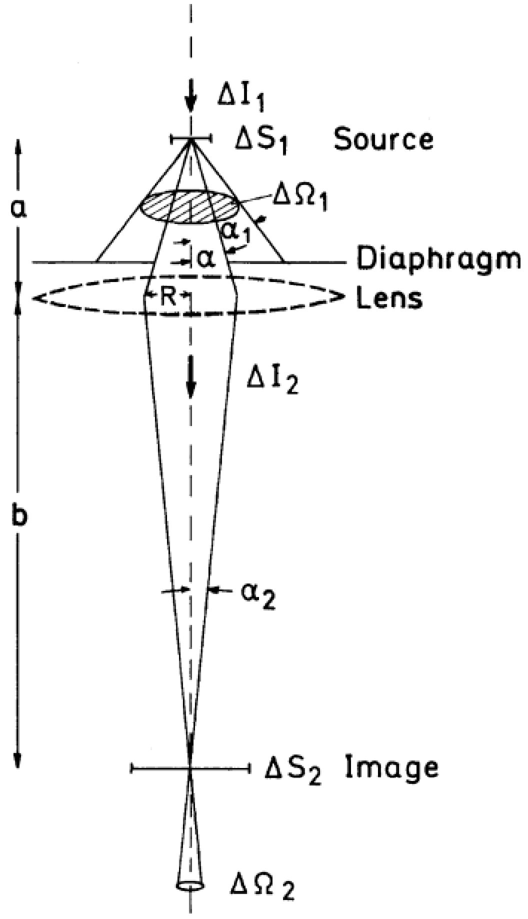
Energy spread

- Caused by electrons from different ‘heights’ leaving the gun
- Different energy electrons are focused differently
- Low energy spread is better





Gun Brightness



$$\beta_1 = \frac{\Delta I_1}{\Delta S_1 \Delta \Omega_1} = \frac{\Delta I_1}{\Delta S_1 \pi \alpha_1^2}.$$

$$\Delta I_2 = \Delta I_1 \frac{\pi \alpha^2}{\pi \alpha_1^2}$$

$\Delta S_2 = \Delta S_1 M^2$
Where M=b/a

$\alpha_2 = \alpha / M$

$$\tan\,\alpha \;\simeq\; \alpha \;=\; R/a \;\text{ and }\; \alpha_2 \;\simeq\; R/b$$

$\alpha_2 = R/b$
$\alpha_2 / \alpha = a/b = 1/M$

Summary

- FEG high energy coherence, and brightness
- Cold FEG has low stability
- FEG need high vacuum

	Units	Tungsten	LaB_6	Schottky	Cold FEG
Temperature	K	2500-3000	1400-2000	1800	300 or 1500
Work function		4.5 eV	2.7 eV	2.7 eV	4.5 eV
Current density		5	10^2	10^4	10^6
Brightness	A/m^2sr	10^{10}	$5x10^{11}$	$5x10^{12}$	10^{13}
Energy spread	eV	3	1.5	0.7	0.3
Diameter of source		20-50 um	10-20 um	15 nm	2.5 nm
Vacuum	Pa	10^{-2}	10^{-4}	10^{-6}	10^{-9}
Stability	%/hr	<1	<1	<1	5
Lifetime	hr	100	1000	>5000	>5000

Next topic

- Magnetic lenses (Williams and Carter, 2009)
- Sample interactions
- Camera
  - CMOS
  - DQE
  - Electron counting
  - Comparison (now K3)
- Grids