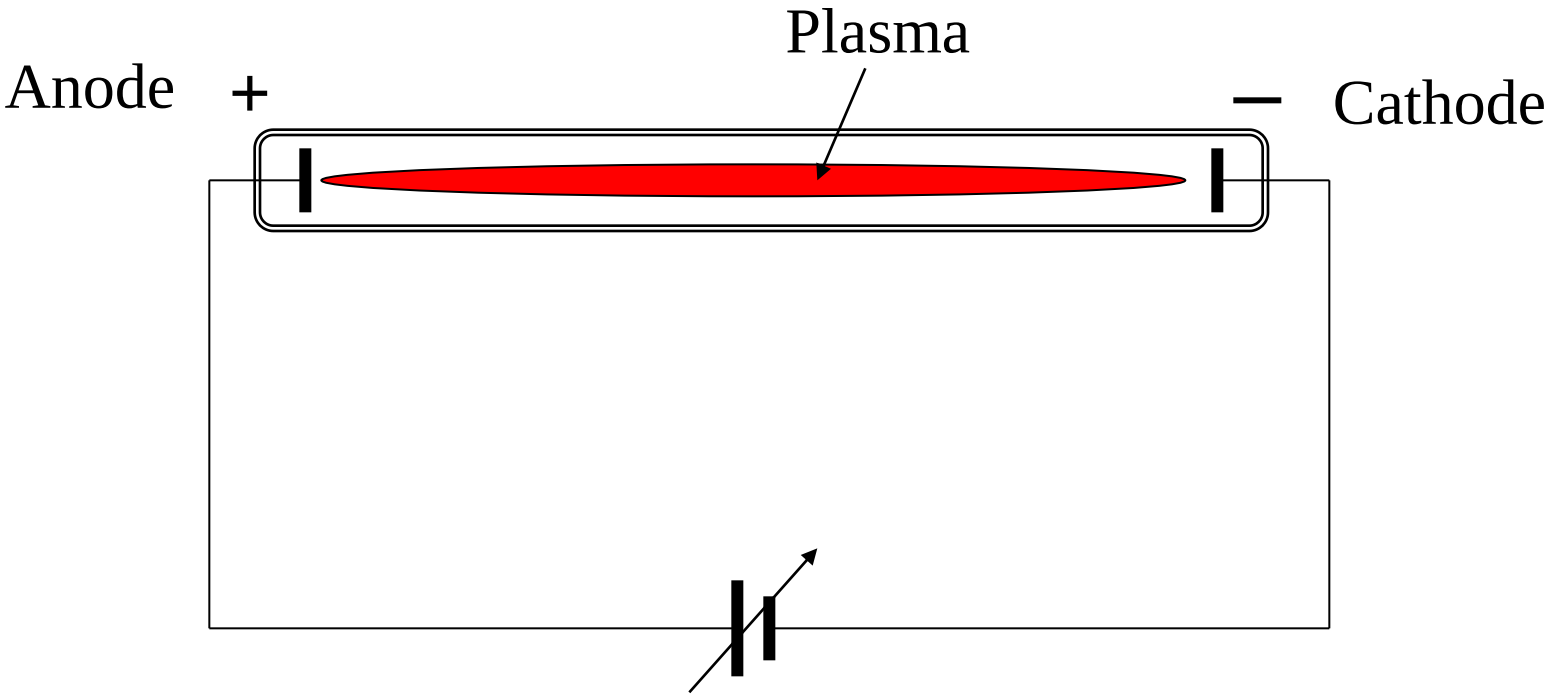
EE 403/503
Introduction to Plasma Processing

Electrodes

October 26, 2011

Midterm

Electrodes



Cathodes

Cathodes are the source of electrons for the electric discharges.

Choice of cathodes:

-emission uniformity
- life time
- operating temperature
- current density
- emission continuity

Basic type of cathode emission mechanism:

- Thermoionic emission
- Field emission
- Secondary emission

Thermoionic Emission

1- Fermi_Dirac Distribution

2- Work Function

3- Richardson Equation

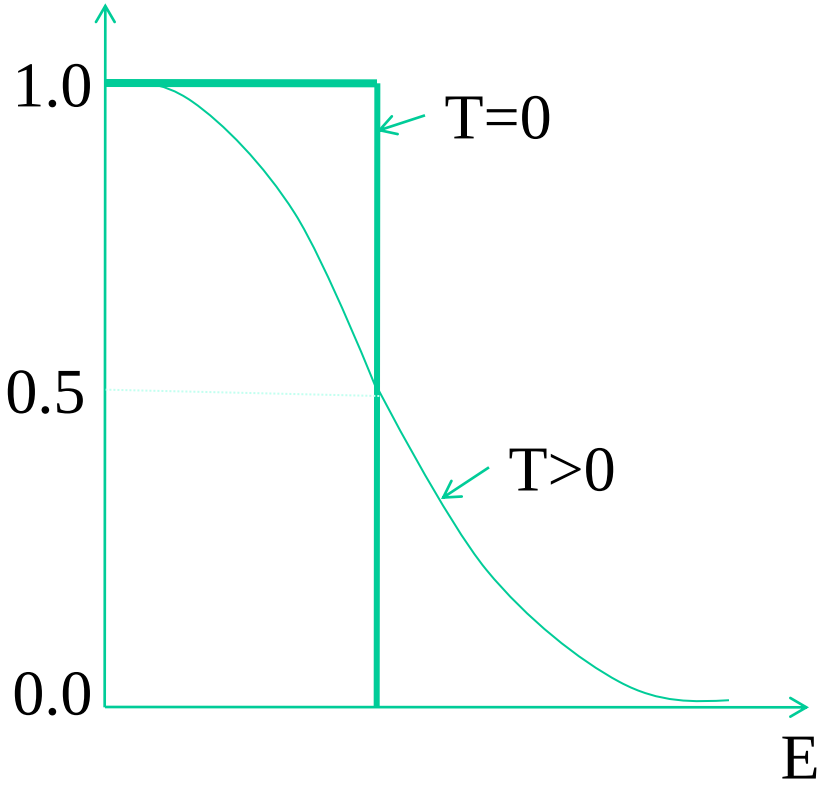
4- Combined Thermoionic and Field Emission

5- Tunnel Effect

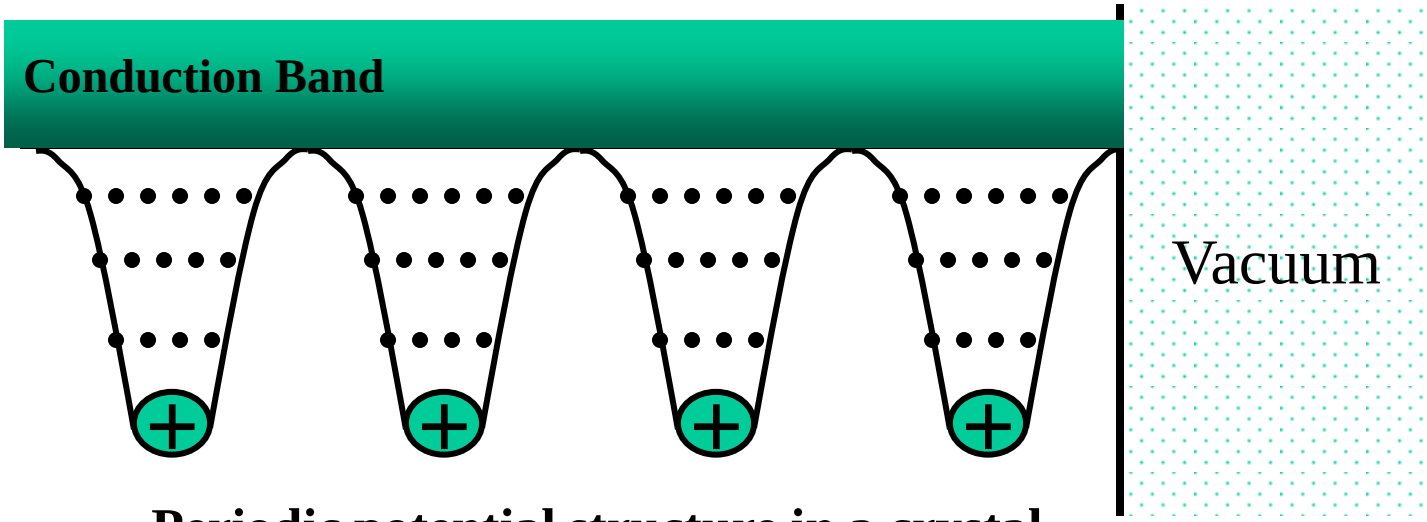
Fermi_Dirac Distribution

The Fermi distribution function:

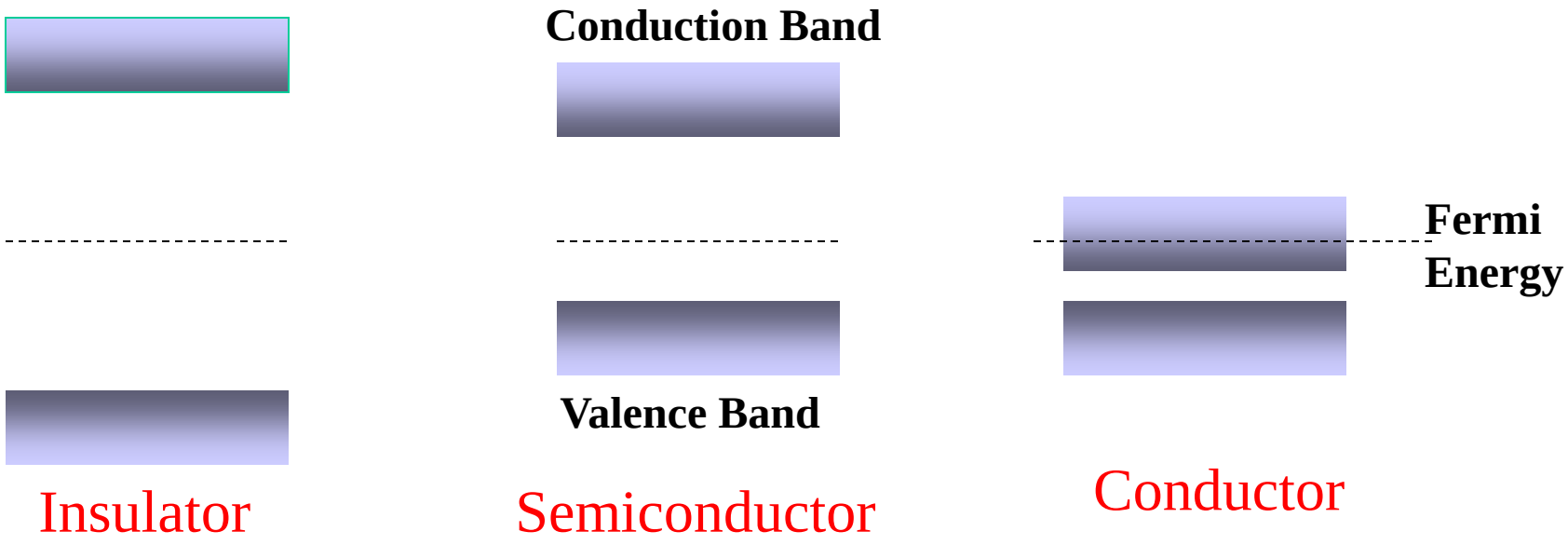
$$f(E) = \frac{1}{1 + e^{\frac{E - E_f}{kT}}}$$



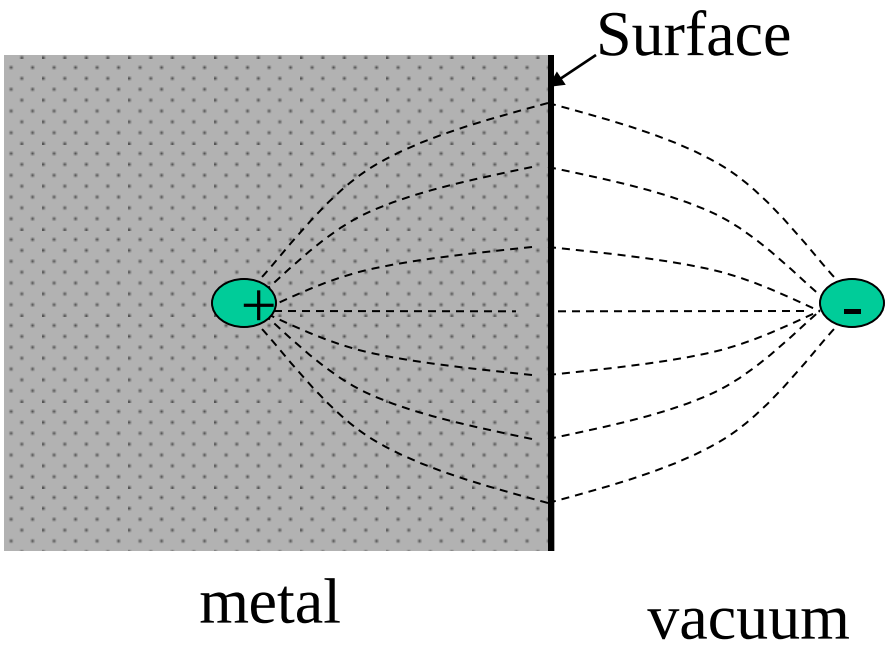
where, E is the electron energy, E_f is the Fermi energy, and T is the absolute temperature. Its physical meaning is that: **f(E) is the probability of occupancy for an electron energy state at energy E by an electron**



Periodic potential structure in a crystal



Work Function



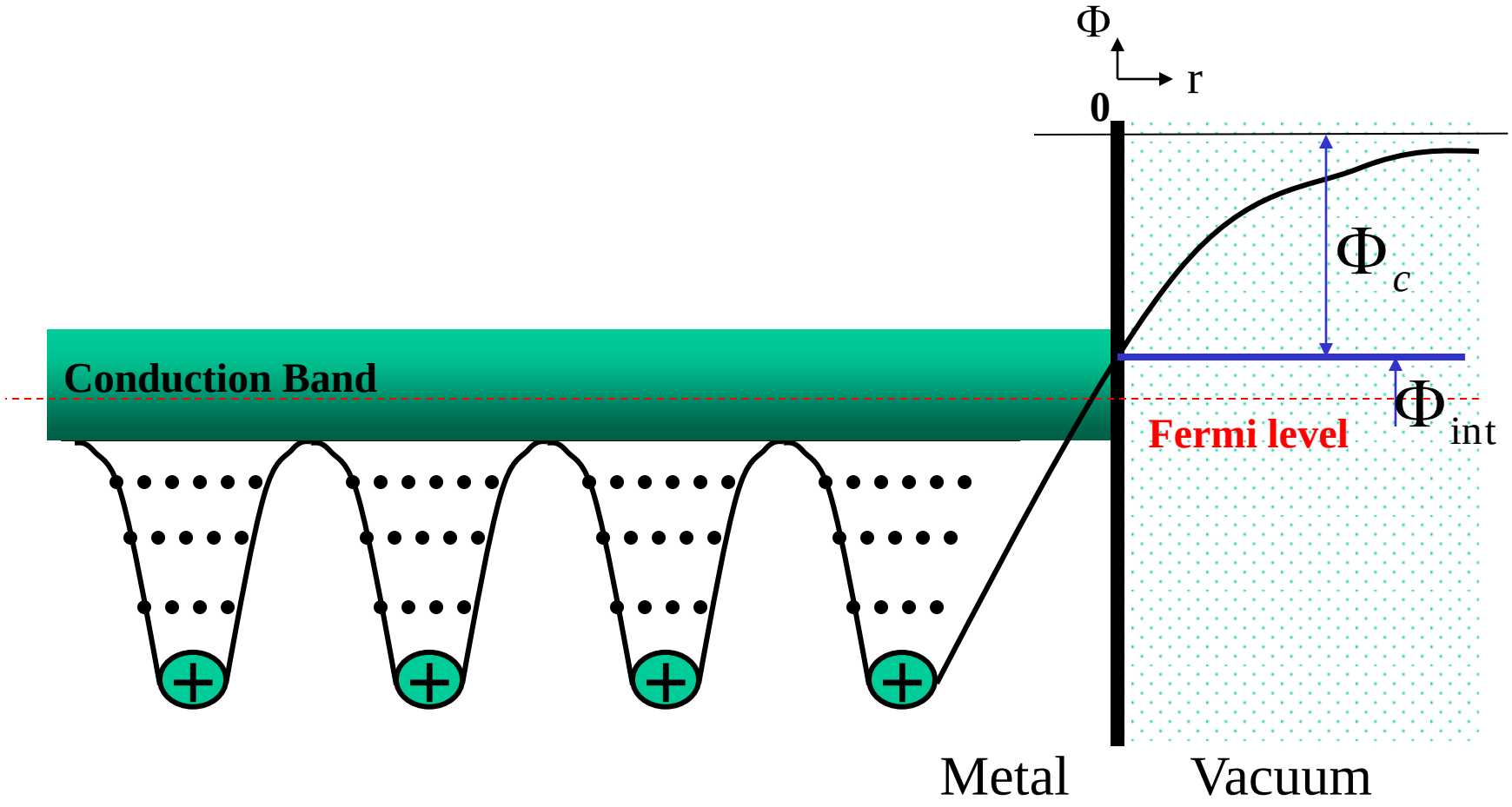
$$F = -\frac{e^2}{(4\pi\varepsilon_0)(2r)^2}$$

$$\chi_c = \int_{r_0}^{\infty} F dr = \frac{-e^2}{(4\pi\varepsilon_0)4r_0} = -e\Phi_c$$

r_0 is roughness of the surface and is in the order of Å

$$\Phi_c \approx \frac{1}{r_0}$$

r_0=1Å → Φ_c = 0.8898 ~ 1 eV


Φ
r
0
Φ c
Conduction Band
Fermi level
Φ int
Metal
Vacuum

Richardson Equation

$$J = 1.2 \times 10^6 T^2 e^{-\frac{(e\Phi_c)}{kT}} \quad [\mathrm{A/m^2}]$$

Work functions depend on the state of the surface (material, orientation and combination) and its temperature.

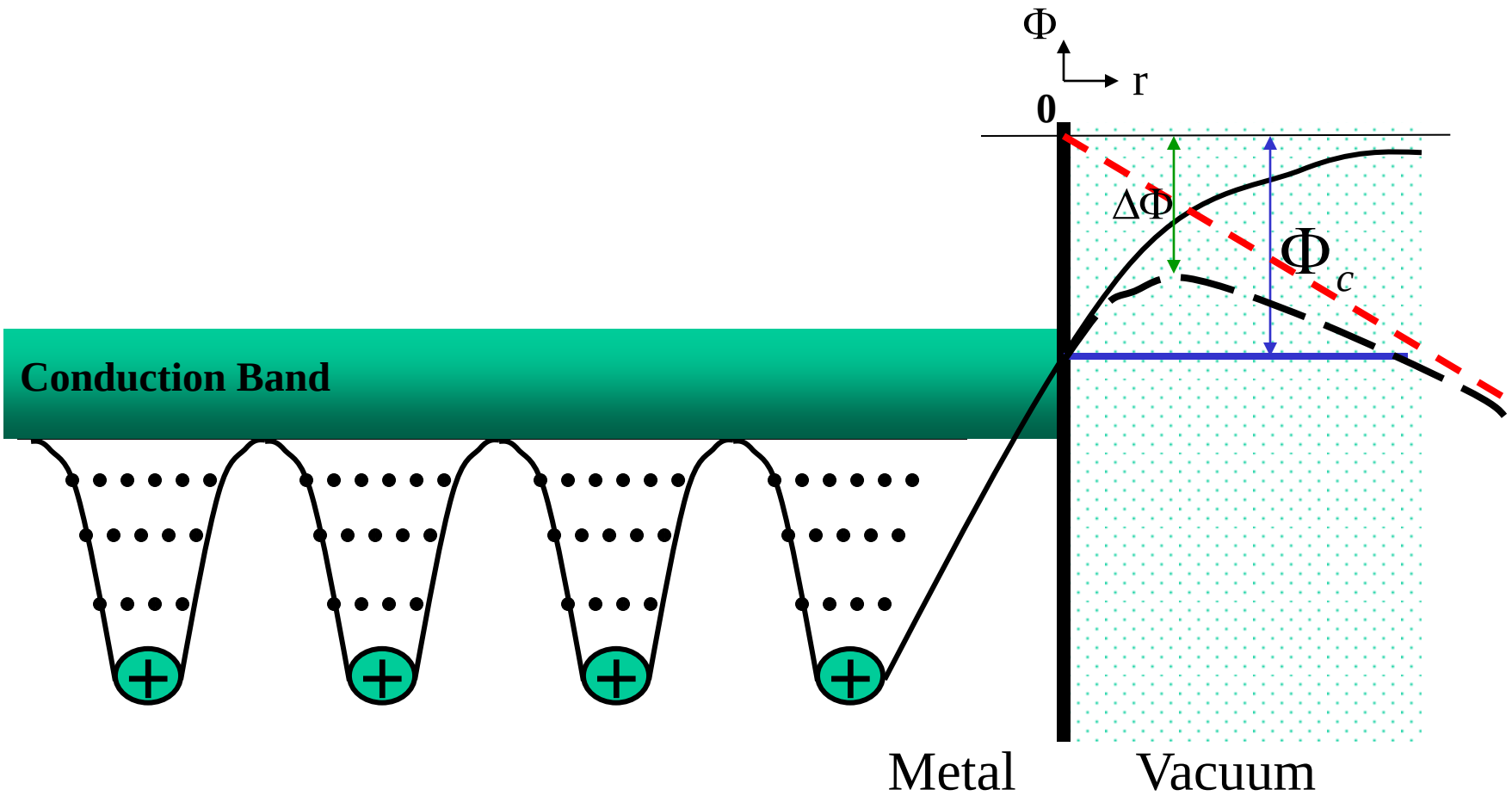
Example: $\Phi_c = \Phi_R + \alpha T$

$$J = (1.2 \times 10^6 \times e^{-\frac{e\alpha}{k}}) T^2 e^{-\frac{(e\Phi_R)}{kT}}$$

$$J = A \times T^2 e^{-\frac{(e\Phi)}{kT}}$$

Material	A	ϕ	Temp (° K)	J (A/cm^2)
Tungsten	60	4.54	2500	0.3
Thoriated W	3	2.63	1900	1.16
Mixed oxides	0.01	1.	1200	1.
Caesium	162	1.81		
Tantalum	60	3.38	2500	2.38
Cs/O/W	0.003	0.72	1000	0.35

Combined Thermoionic and Field Emission



$$J = kT^2 e^{-\frac{e\left(\Phi - \sqrt{\frac{eE}{4\pi\varepsilon_0}}\right)}{kT}}$$

Schottky modification

$$J = kT^2 e^{-\frac{e\left(\Phi - \sqrt{\frac{eE}{4\pi\varepsilon_0}}\right)}{kT}}$$

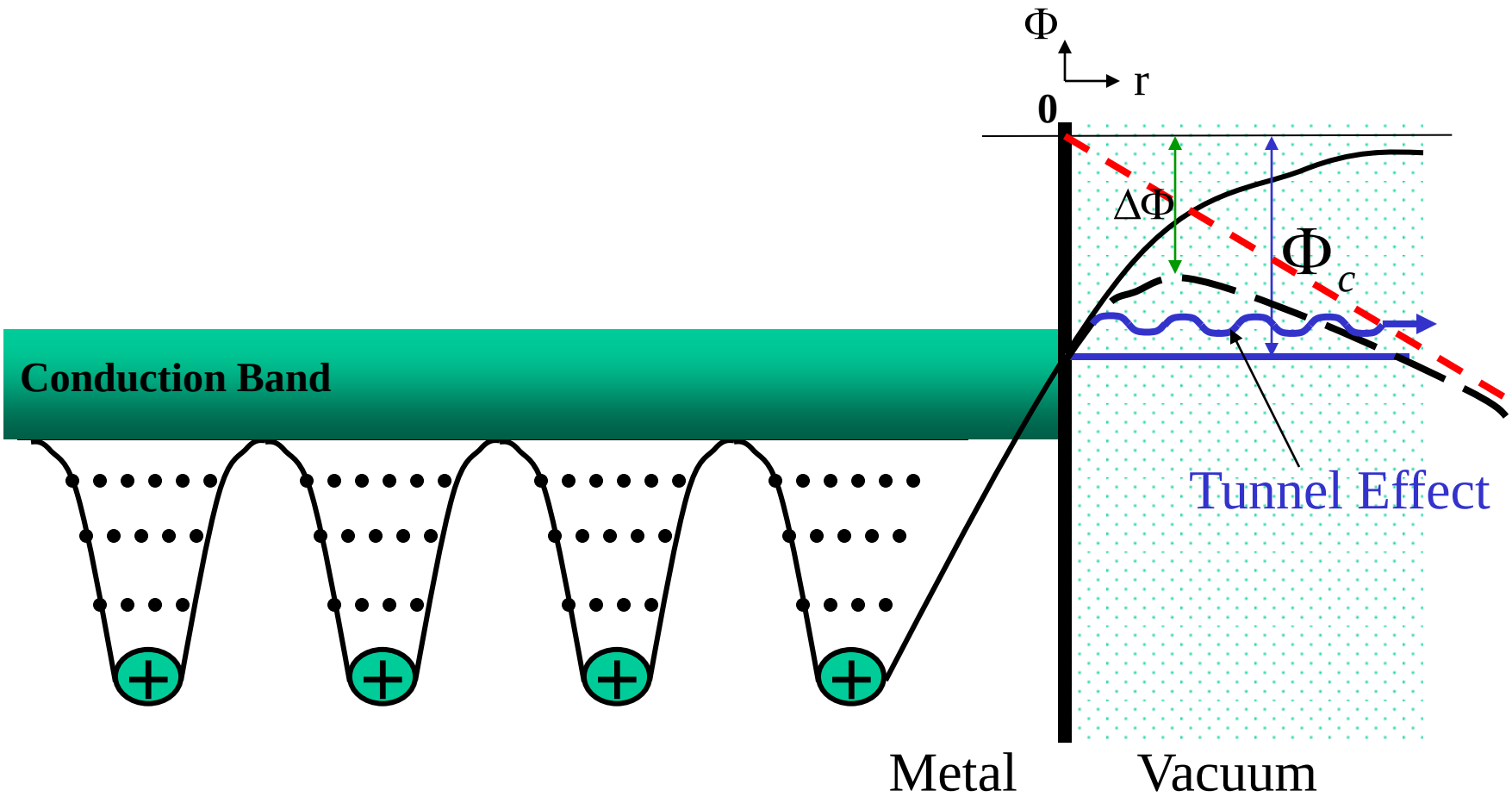
Maximum lowering could be equal Φ_{Max}

$$\Phi_{Max} = \sqrt{\frac{eE}{4\pi\varepsilon_0}}$$

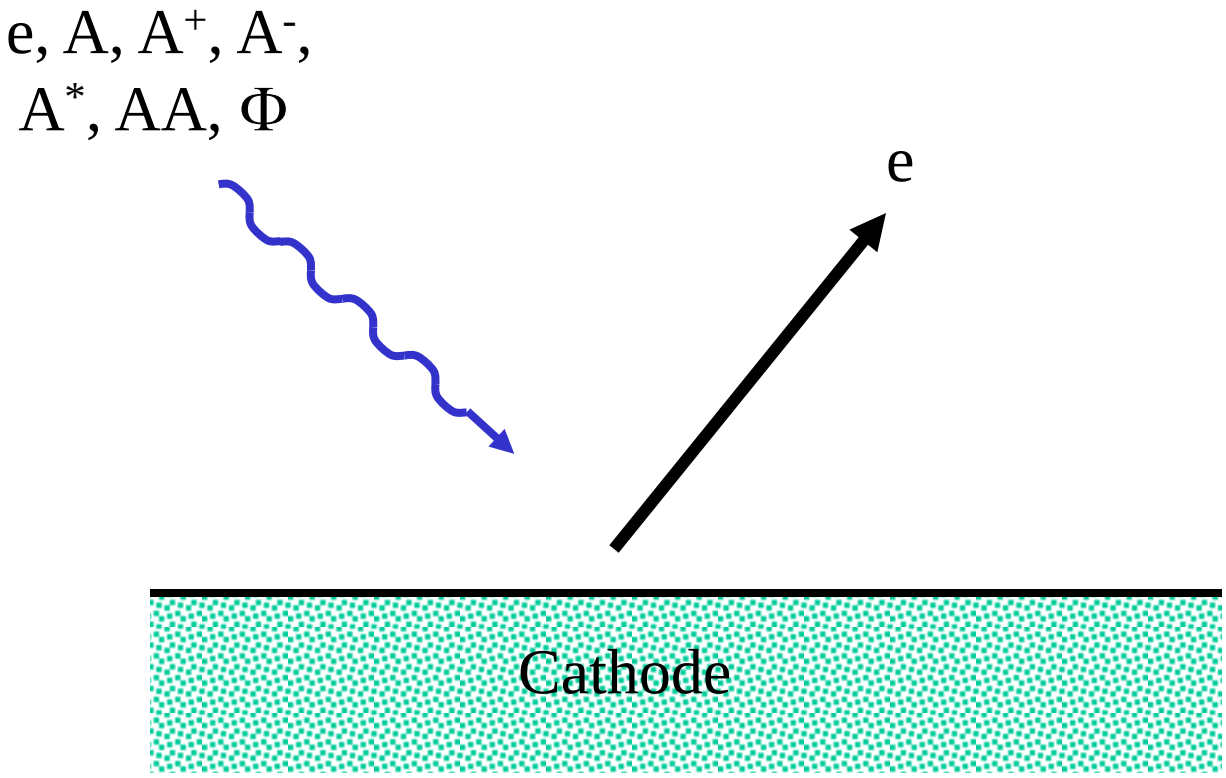
$$\Phi_{Max} = 4.5 \Rightarrow \quad E = \frac{\Phi^2 (4\pi\varepsilon_0)}{e} = 1.41 \times 10^{10} \qquad V/m$$

In practice E ~ 10^8 – 10^9 V/m

Tunnel Effect



Secondary Emission

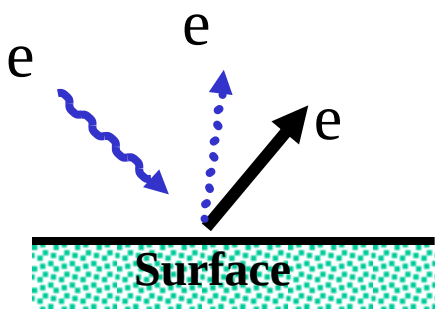


Electron Emission by Electron impact

The secondary electrons are emitted in random direction with velocities of a few volts even the primary have thousands of volts.

The emission of secondary electrons increases with increasing energy of the primary electrons to a maximum and then decreases with increasing energy of the primary electrons.

Elements	$\delta_{at\ Max}$	$Volts_{at\ Max}$	Voltage for $\delta=1$
Al	1.9	220	35
Au	1.14	330	160
Cu	1.32	240	100
Fe	1.30	350	120
Mg			80
Mo	1.30	360	120
Ni	1.30	460	160
Pt			250
W	1.45	700	200

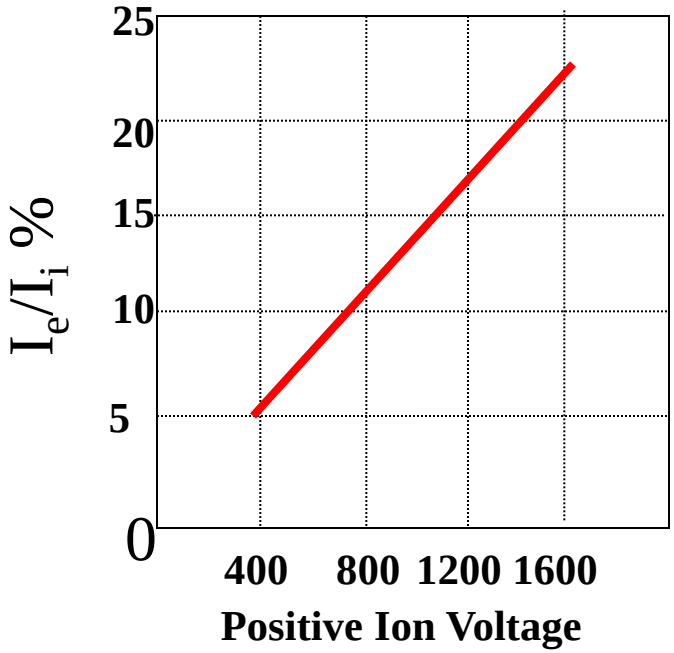


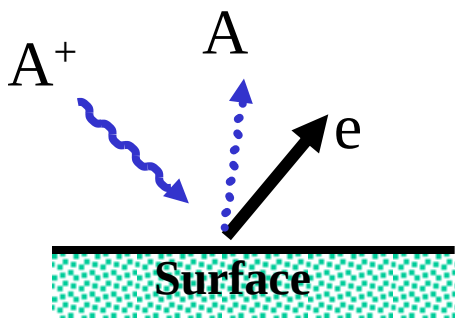
Number of Secondary Electrons, δ, Emitted per Primary Electron

Electron Emission by Positive-ion impact

To cause secondary emission, the ion, upon impact, must extract two electrons of which one is necessary to neutralize the ion. Therefore, its potential energy must be at least twice the work function of the surface.

Emitted electrons have energies in the order of 1 to 2 volts.





Variation of secondary-electrons emission from hot nickel target

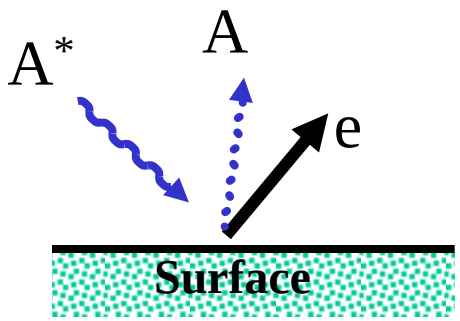
Ion impact also causes deposition, sputtering or ion implantations

Electron Emission by Metastable Atoms

Metastable atom impact on the surface eject electrons with energies varying from 2 volts to a maximum value equal to the difference between the energy of the metastable state and the work function of the surface.

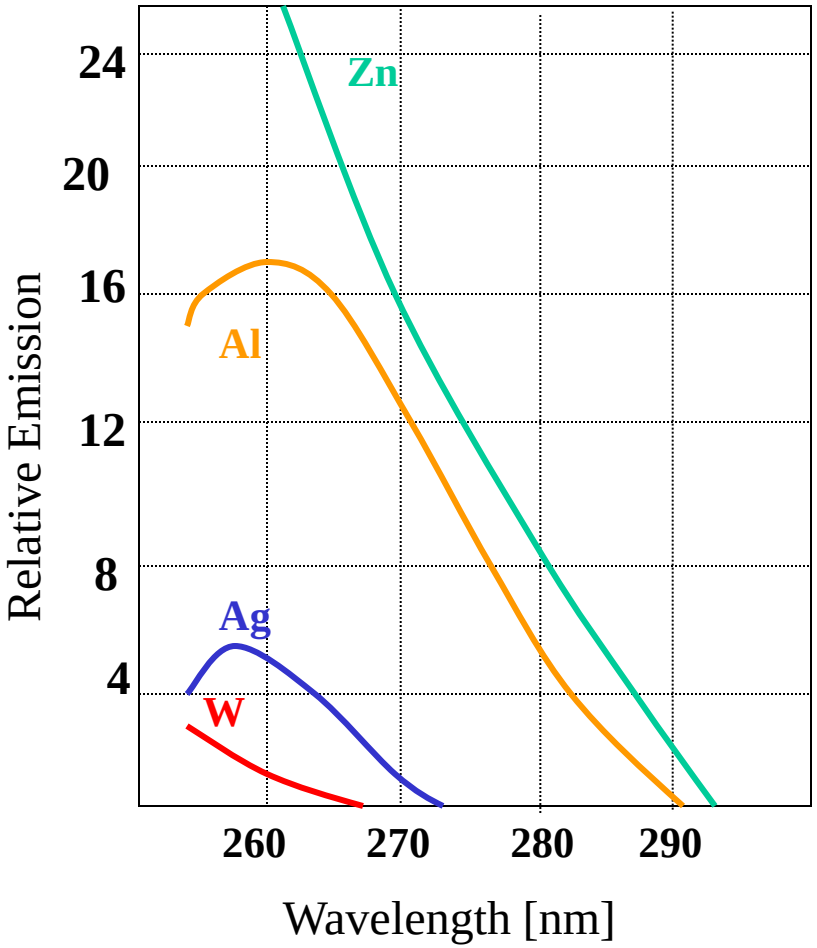
There appears to be no relation between the energy of the secondary electrons and the kinetic energy of the metastable atoms.

The probability of emission is of the order of several per cent.

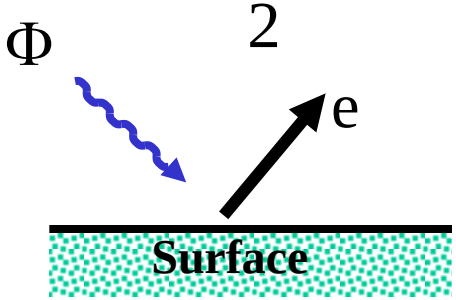


Electron Emission by Photons

Photoelectric work function $\Phi = \dfrac{12{,}336}{\lambda_0}$ ← Threshold wavelength



$$\frac{mv^2}{2} = h\nu - e\Phi$$



Type of Cathodes

1- Pure metal emitter (old radio tubes)

2- Oxide coated or doped cathodes

3- Thoriated tungsten

4- Dispenser cathodes

Anodes

Anodes are usually playing a passive role in the discharge

An electron space charge exist immediately in front of the anode. As a consequence, there is a potential drop at the anode

No positive ions are emitted by the anode.

The anode acts like a probe with respect to the plasma and would be expected to receive the random positive-ion and electron currents from the positive column.

At atmospheric pressure the current density can have values between 100 to 100,000 A/cm^2, and anode volatge drops may have values of 0 to 10 V.

Scaling up total emission current from Field Emitter Arrays

Work function

COMBINED THERMIONIC AND PHOTOELECTRIC EMISSION FROM DISPENSER CATHODES