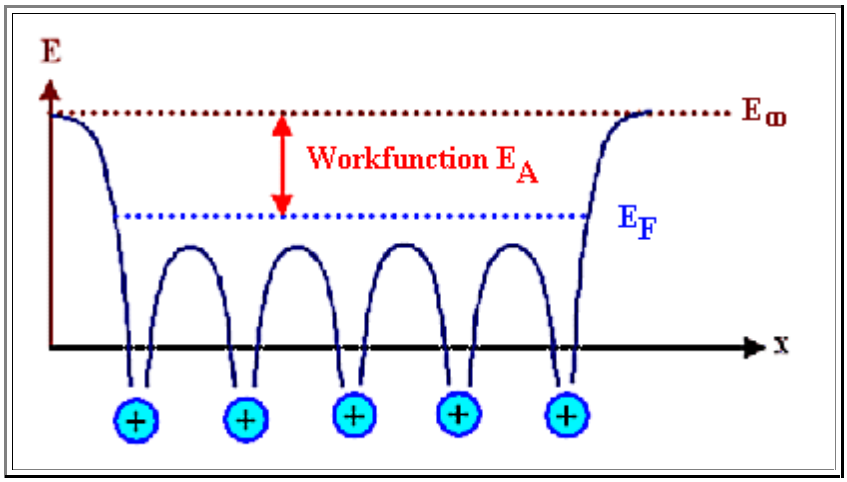
2.3. Special Applications

2.3.1 Thermionic Emission

- **Cathodes** in **cathode ray tubes** (***CRT***), in regular **electron tubes** (still used for special applications), but also in all electron beam tools as e.g. *electron microscopes* or *electron beam welding*, are one example of *special conductors*. We need to have free electrons in the material *and* we need to extract them from the material.
  - For good cathodes we wish for some specific properties: First we want to extract lots of electrons *easily* and in *large quantities* (i.e. we want high current densities for little money).
  - Second, we want to extract them from a very *small area* (for high brightness), so that we can consider the electron beam to come from a *point source* which makes (electron) optics a lot less complicated to handle!
- Lets look at the free electron gas model and see how we can extract electrons in general.



  - For a metal, there are lots of electrons in the last band at all energies up to the Fermi energy, and at very low temperatures it takes at least the energy E_A to push an electron up the energy scale to E_∞, where it would be free to go wherever it wants - it is no longer "bound" to the crystal. We call that particular energy the ***work function*** of the material.
- The **work function** E_A of the material is thus the decisive quantity; it is the difference between the **Fermi energy** and the potential at infinity E_∞.

$$E_A = E_F - E_\infty$$

  - If we let $E_\infty = 0$ and have the energy scale going "down", we simply have .

$$E_A = E_F$$

- The current density for thermionic emission is given by the well-known **Richardson equation**, which we obtain by calculating how many electrons will have sufficient energy to overcome the energy barrier to the outside world from the energy distribution of electrons in a free electron gas model.
  - The necessary calculation is a meaningful mathematical exercise but we skip it to save time
- The Richardson equation for the current density j from a hot surface states writes:

$$j = A \cdot T^2 \cdot \exp - \frac{E_A}{kT}$$

  - From measuring $j = j(T)$ we expect (almost) **Arrhenius** behavior; E_A then follows from the slope of the plot, the constant A from its intersection with the j - axis.
  - If you are unsure about what this function looks like, use the function generator and play a bit.
  - The pre-exponential factor A can be calculated from the free electron gas model, but than it is only a crude approximation for real materials. Its free-electron-gas value is:
    $A_{theo} = 120\ A \cdot cm^{-2} \cdot K^{-2}$.

Lets compare that to some measured values (and bear in mind that ***A*** may depend on the Miller indices of the crystallographic plane from which we extract electrons, too - so numbers vary):

Material	**Fe**	**Ni**	**Pt**	**Ta**	**W**	**Cs**	**LaB_6**
A [$Acm^{-2}K^{-2}$]	26	30	32	55	60	162	25
E_A [eV]	4,5 - 4,8	5,15 - 5,35	5,65	4,15 - 4,8	4,2	1,8 - 2,14	2,6
T_m [^oC]	1 535	1 452	1 755	2 850	3 410	28,4	2 210

Cs has the lowest work function, but its melting point is so low that it is of no use. Optimizing everything, the winners are:

- **W**, the workhorse for cathode materials.
- **LaB_6**, a rather exotic material, because single crystals with very fine tips can be made that provide high current densities from a very small area. This is important whenever you want to focus the electron beam on a "point", e.g. in scanning electron microscopes. The focal point cannot be smaller than the area from where the electron beam was extracted from - *and you like it to be in the **nm** region*. The price one has to pay for this (besides for the **LaB_6** cathode, which is not cheap), is that the cathode has to be run in ultra high vacuum (***UHV***), because the fine tip would otherwise soon be damaged by ion bombardment resulting from ions extracted out of the residual gas atmosphere.

Questionaire

Multiple Choice questions to 2.3.1 (and 2.3.2)