Lecture 6

Reading Material

Reading:

Finish Chapter 6 Solymar and Walsh

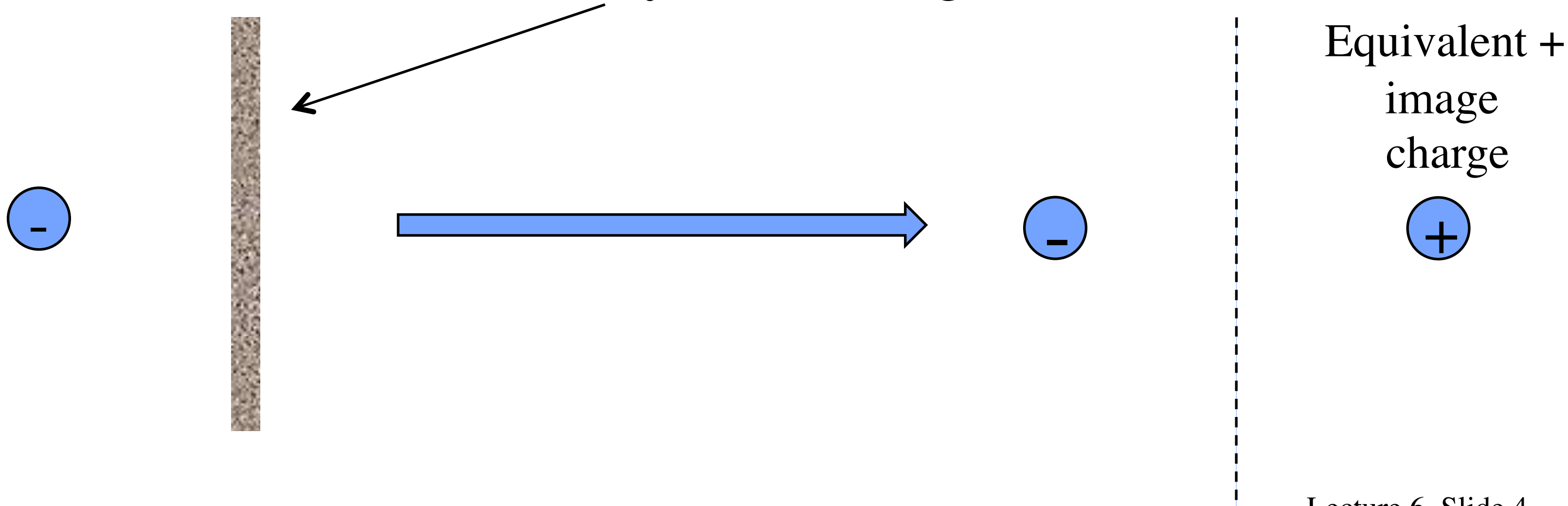
Chapter 7 Solymar and Walsh

Thermionic Emission

- Note the dependence on temperature and the value of the work function. A_0 is constant. There is an exponential dependence on temperature.
- In reality, electrons that escape the metal will have several mechanisms to be attracted back (e.g. electrostatic forces from positively charged surface) so we need to replenish the electrons with an external circuit. Putting the metal in a vacuum will also improve emission.

The Schottky Effect

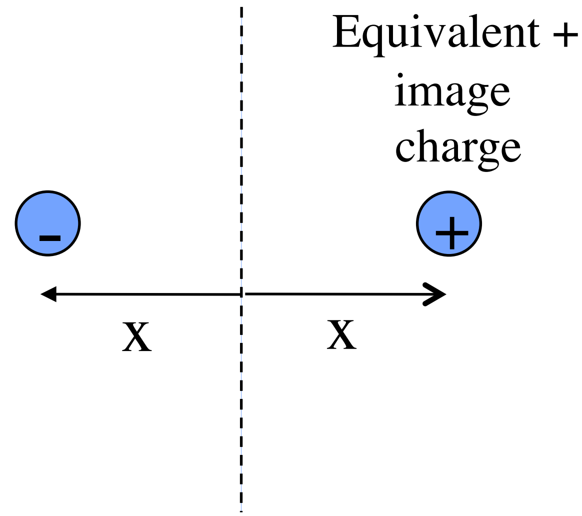
- Modification of thermionic emission can be done using a clever trick from electrostatics
  - Include and image force
  - Include an electric field
- Create an equivalent model of the forces that act on an electron next to an infinitely conducting sheet



The Schottky Effect

- The force on between the two charges is well known

$$F = \frac{q^2}{4\pi\varepsilon_0}\frac{1}{r^2} = \frac{q^2}{4\pi\varepsilon_0}\frac{1}{(2x)^2}$$



- The potential energy is found by integrating the force from x to infinity

$$V(x) = \int_x^\infty F(y)dy = \frac{q^2}{16\pi\varepsilon_0}\int_x^\infty \frac{1}{(y)^2}dy = -\frac{q^2}{16\pi\varepsilon_0 x}$$

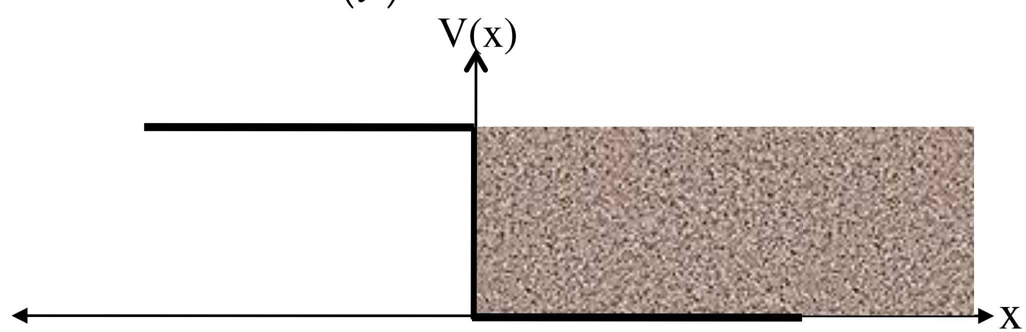
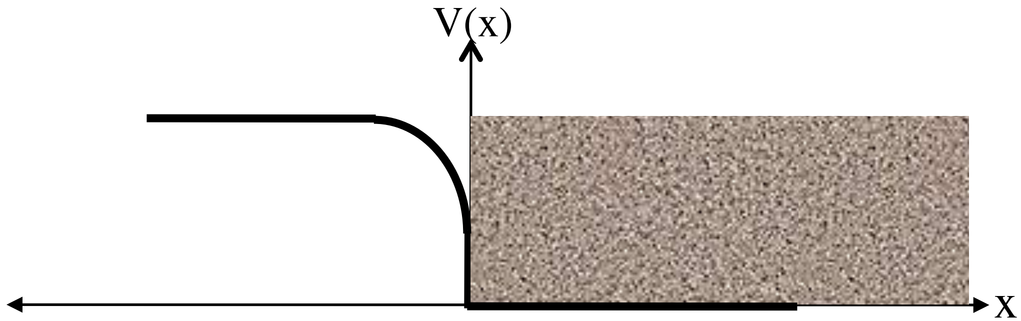


Image Effect

- Using the square law force of the image charge, the metal/vaccum barrier can be redrawn as



- Now what happens if we apply an external electric field

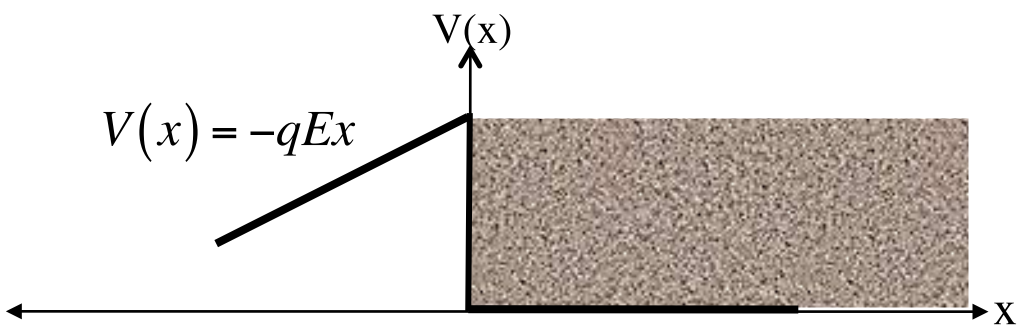


Image Effect for modeling Schottky Effect

- Now we have to sum the applied field with the mirror charge field

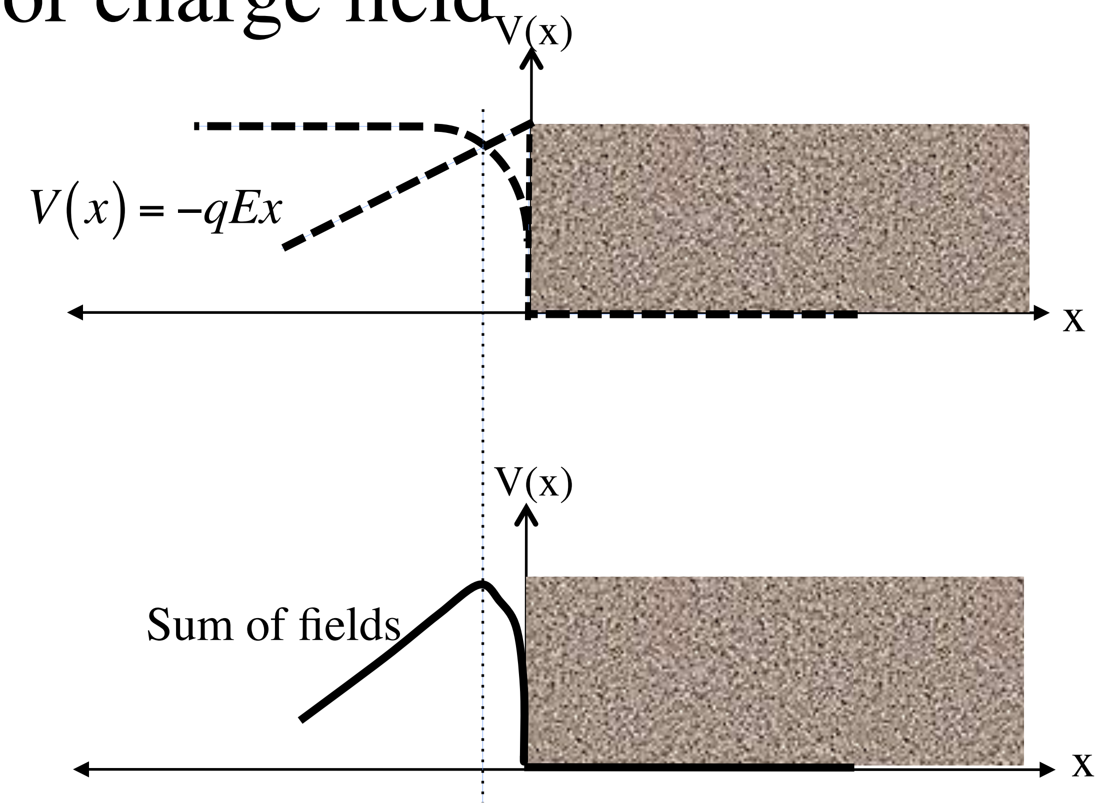


Image Effect for modeling Schottky Effect

- The maximum is obtained by differentiating the potential and setting equal to zero

$$\frac{d}{dx}\left(\left(\frac{q^2}{16\pi\varepsilon_0 x} - qEx\right)\right) = 0$$

$$V_{Max} = -q\left(\frac{qE}{4\pi\varepsilon_0}\right)^{1/2}$$

- This reduces the work function we talked about before to an effective work function

$$\phi_{eff} = \phi - q\left(\frac{qE}{4\pi\varepsilon_0}\right)^{1/2}$$

Thermionic Emission with Schottky Effect

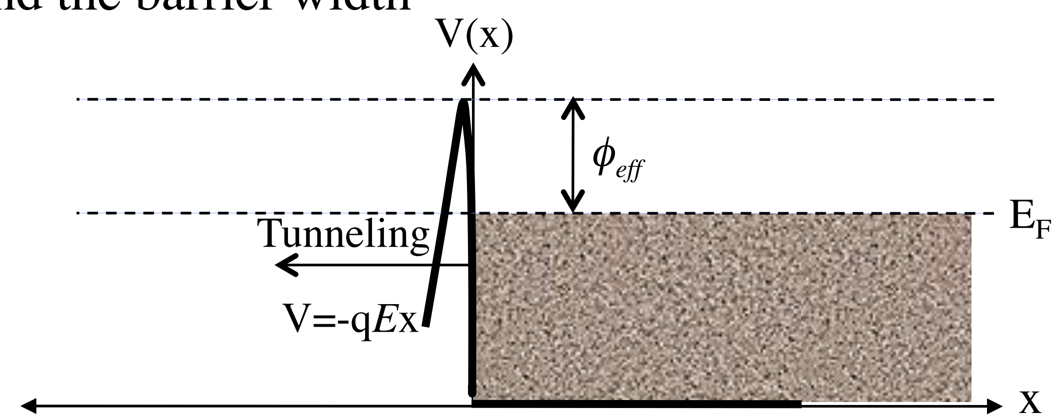
- The current due to thermionic emission can now be correct to include the Schottky Effect. The reduction in the work function is due to the Schottky effect which can be experimentally observed. The end result is that more electrons can escape easier than predicted and the current increases because the barrier is lower

$$J = \frac{4\pi q m k_B^2}{h^3}(1-r)T^2 \exp\left({-(\phi_{eff})} \Big/ {k_B T} \right)$$

$$= \frac{4\pi q m k_B^2}{h^3}(1-r)T^2 \exp\left({-\left(\phi - q\left(\frac{qE}{4\pi\varepsilon_0}\right)^{1/2}\right)} \Big/ {k_B T} \right)$$

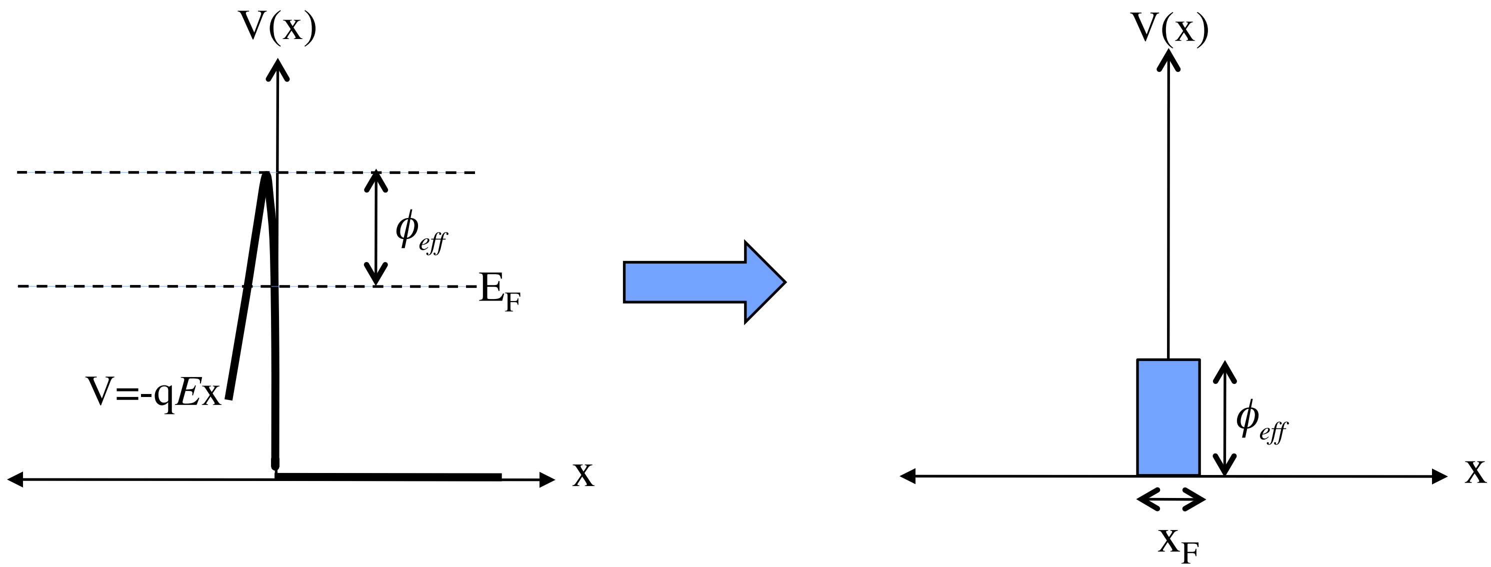
Field Emission

- Due to the lowered potential barrier between the metal and vacuum (Schottky effect), the current increases.
- If we continue to increase the electric field strength, the electrons can now "tunnel" through the barrier in addition to escaping over it. The higher the applied field, the more reduced the barrier thickness and the higher probability of tunneling
- Whereas the Schottky effect was temperature dependent, this effect called "field emission" is not temperature dependent. It is dependent on the field strength and the barrier width



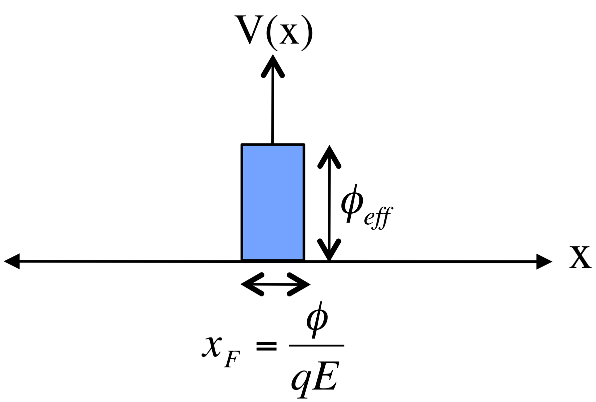
Field Emission

- The narrowed barrier can be modeled as an effective barrier of height ϕ_{eff} and width x_F.



Field Emission

- ➢ The width of the barrier is $x_F = \dfrac{\phi}{qE}$
- ➢ The tunneling current may be approximated by



$$J \approx \exp\left(-\frac{\left(2\phi_{eff}\right)^{1/2}}{\hbar} x_F\right) = xp\left(-\frac{\left(2\phi_{eff}\right)^{1/2}}{\hbar}\frac{\phi}{qE}\right)$$

$$\approx \exp\left(-\frac{(2m)^{1/2}}{\hbar e}\frac{\left(\phi_{eff}\right)^{1/2}\phi}{E}\right)$$

Function of E not T

The Photoelectric Effect

- Electrons can also be removed (emitted) from the surface of a metal by an incident electromagentic wave – the “photoelectric effect”
- A photon of frequency ω carriers energy

$$E_P = \hbar\omega$$

- If the photon energy is greater than or equal to the work (or effective) function, then an electron can be emitted from the metal.

Chapter 7 – Band Theory of Solids

- How does the behavior of solids like insulators and semiconductors differ from that of metals?
- The electrons are not all free, rather all or some are bound and none or some are free.
- Bound electrons are referred to as Valance electrons (there are really other bound electrons but the ones that require the least energy to break free and have available states to go into are the valance electrons.
- Free electrons are referred to as conduction electrons
- At one extreme – Insulators have no free electrons and are poor conductors and metals have no bound electrons and are good conductors. Semiconductors lie in the middle.

The Kronig-Penney Model

- Proposed in 1930, assumes a certain shape potential distribution inside the solid for the Schrodinger equation.
- Whereas in the free electron model the potential is uniform, the K-P model takes into account a variation in potential due to the atomic material lattice.
- Consider first the one dimensional case which has the following features
  - The potential has the same period as the lattice
  - The potential is lower near the lattice ions and higher in between the lattice ions.

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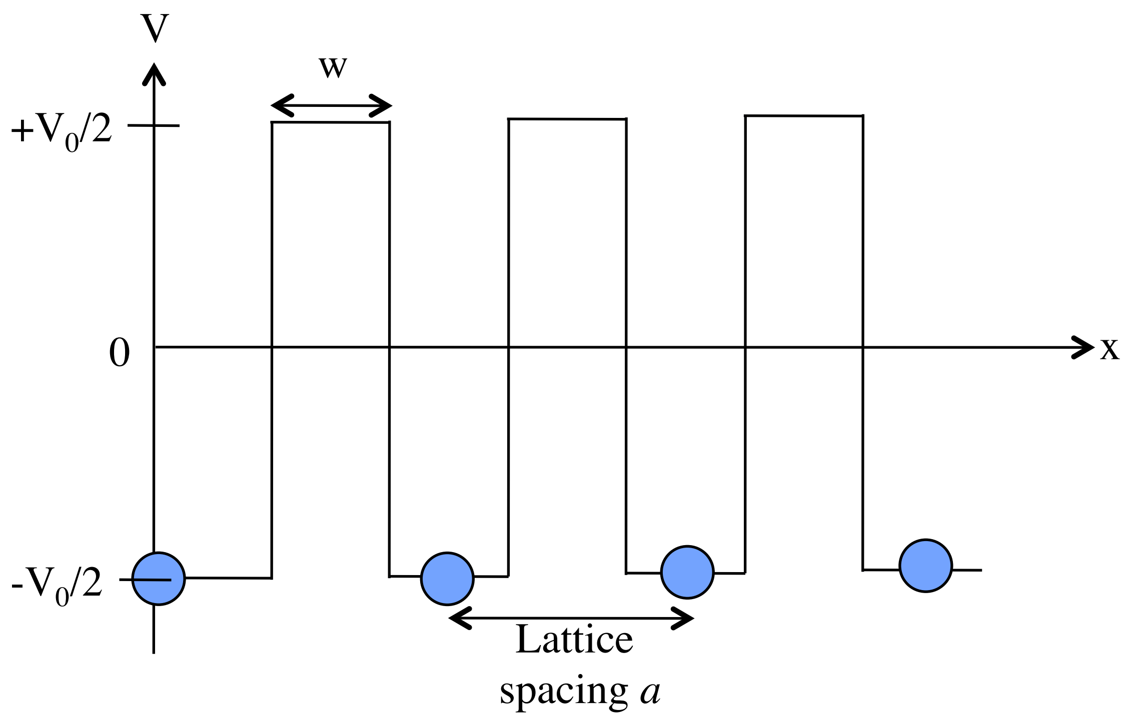

The Kronig-Penney Model

- Now consider the time dependent Schrodinger equation and lets insert our model for the potential as a function of x (for the one dimensional case)

$$\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2}+\left[E-V(x)\right]\psi=0$$

- Solving for the two cases $V(x) = +V_0/2$ and $V(x) = -V_0/2$ separately (piecewise linear) and matching the solutions at the boundaries (continuity), assume the wave-functions have the form (called a Bloch mode which we will look at later)

$$\psi_k = u_k(x)e^{ikx}$$

- Next lecture we will solve this solution and look at the Ziman and Feynman models and introduce the effective mass.