Lecture 11: Chapter 28, October 6 2005

The Electron Current

Simple material for reading, pp.879-896.
We will consider major points.

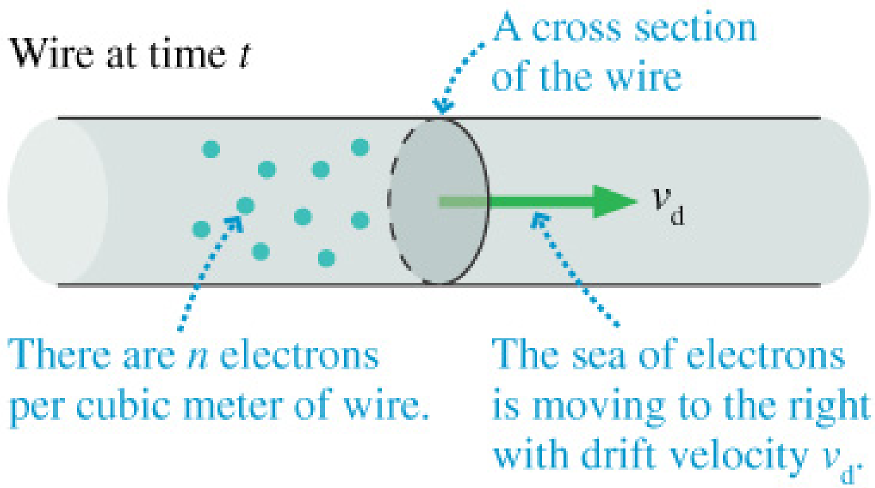
- The definition of current is given on page 890:
I = *dQ*/*dt* [1 Ampere = 1 coulomb per second]

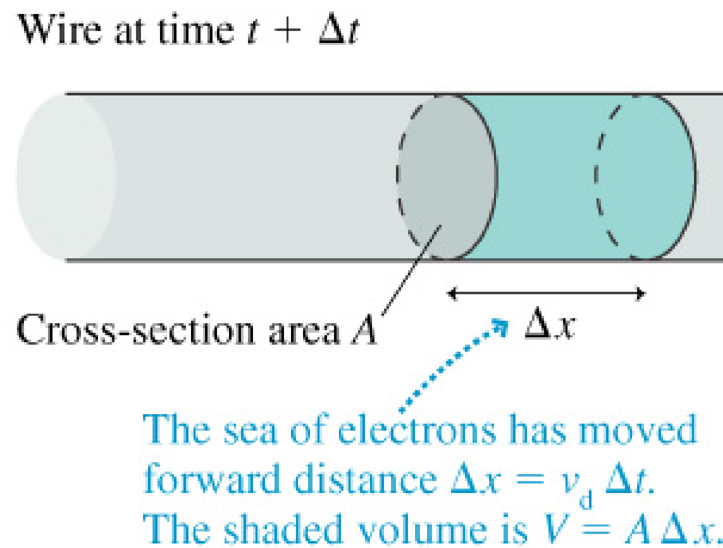
- Don't be confused with the use of parameter *i* called "current", *i* = *I*/*e,* in the text. As a current we will use only *I*.

- Sometimes we can use small *i* for current, but in the same sense as *I*, not as *i* = *I*/*e.*

- Although the current *I* (or *i*) can be thought as a vector we will consider only its *magnitude*: *I* = *i* = *dQ*/*dt*

Drift of Electron Gas





Assumption: electrons drift with *constant* velocity (v_d) in the electric field. At the first sight they should accelerate, but the constant velocity can be achieved due to "friction" caused by their scattering on atoms.

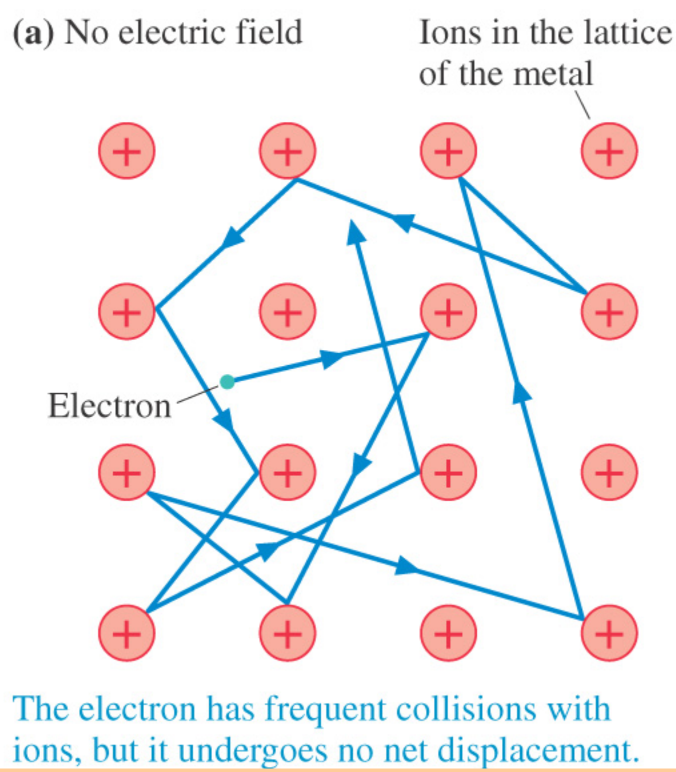
$I = Q/\Delta t = eN_e/\Delta t$ - where N_e – number of particles that pass through a cross section *A*.

Let us introduce concentration *n*. When:

$N_e = nV = nA\Delta x = nAv_d\Delta t \Rightarrow I = e\,nAv_d\,\Delta t/\Delta t = e\,nAv_d$

Microscopic Model Taking into Account Thermal Motion

Thermal Motion

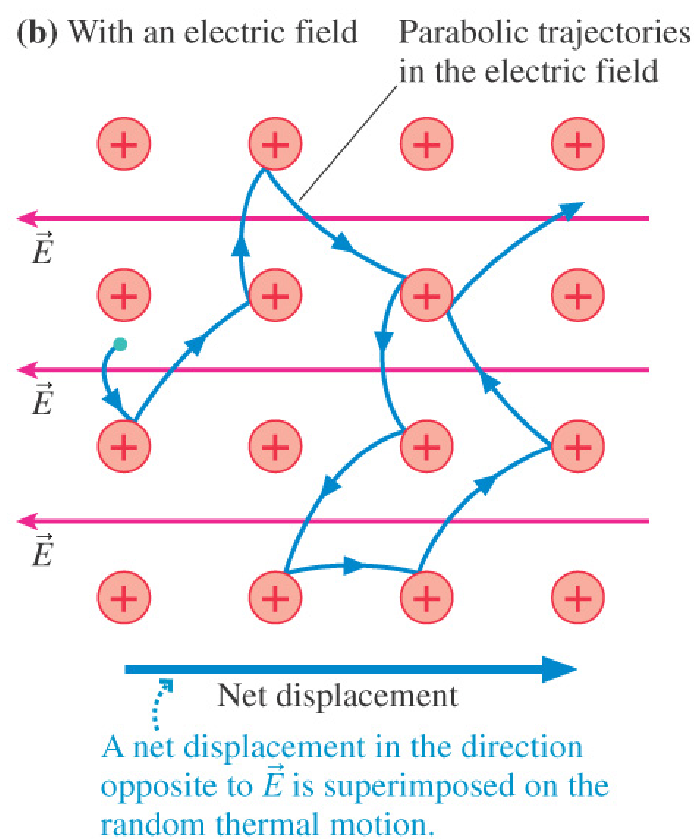


The thermal energy of electrons is 3/2(kT). By requesting

$3/2(kT) = mv_{th}^2/2$

one can estimate average electron speed v_{th} ~10^5 m/s

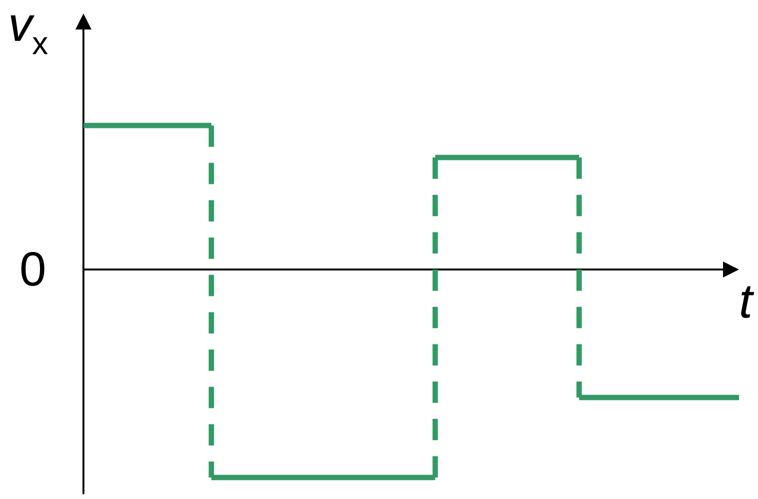
With an electric field



Drift velocity in electric field (v_d) is much smaller than v_{th}. But how to calculate v_d?

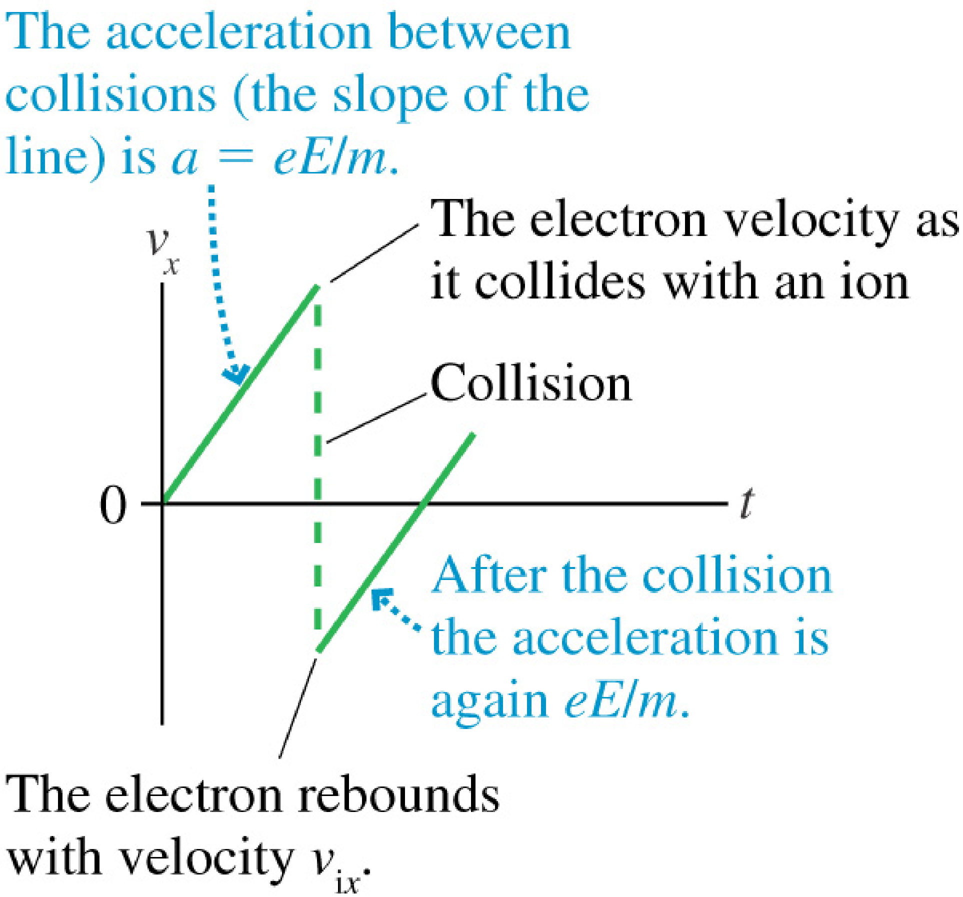
More Detailed View How Current Appears in this Model

Without electric Field



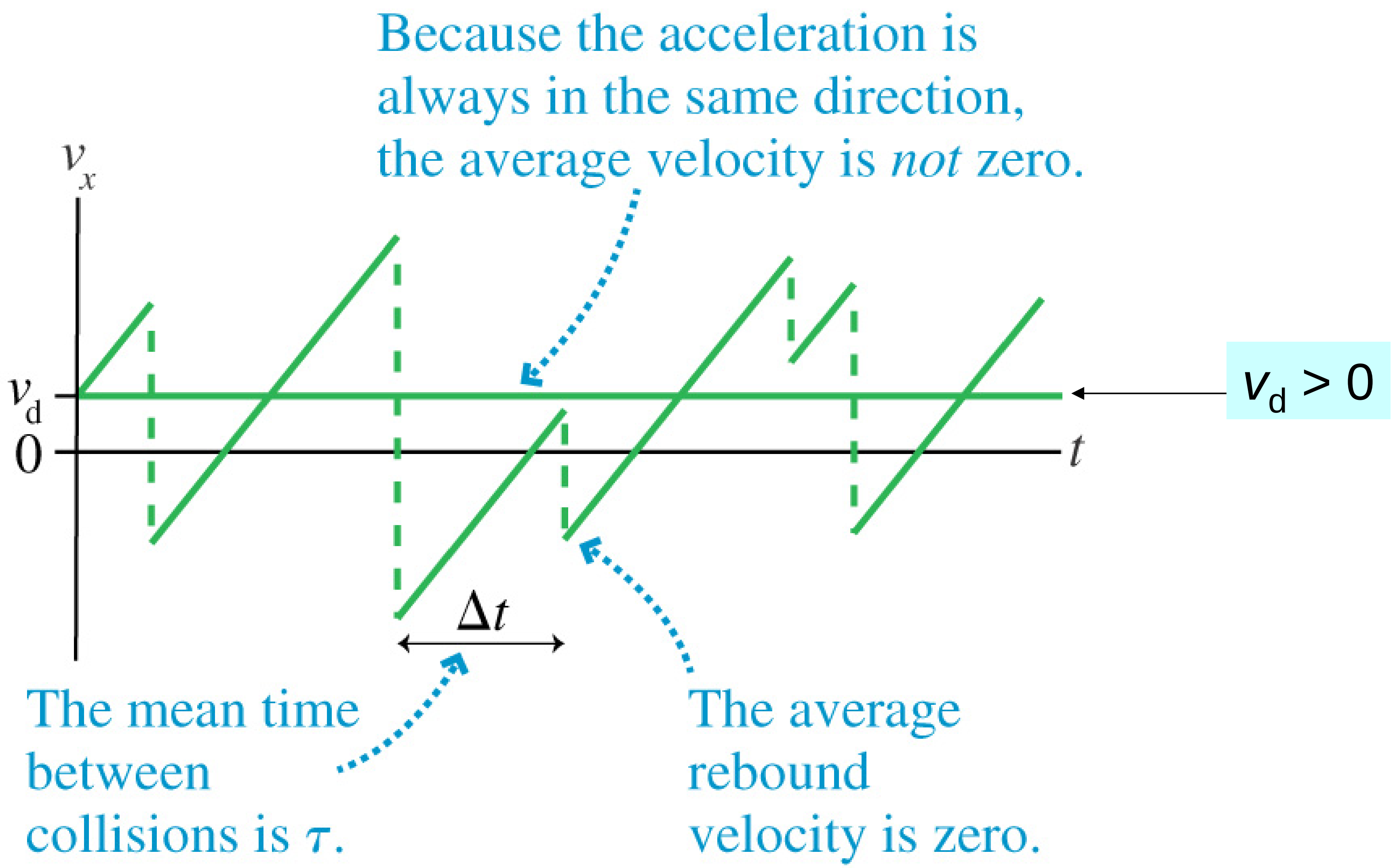
- Between collisions the velocity is constant.
- Each collision leads to a random change in v_x.
- The velocity on average is zero (v_d=0)

With electric Field



Due to the slope the averaging will give a positive velocity (v_d>0).

More Collisions…



Calculating Drift Velocity and Current

Let us express the instantaneous velocity (v_x):

$v_x = v_{ix} + a_x \Delta t$, where v_{ix} – initial velocity after collision
$a_x = F/m = eE/m$

Drift velociy (v_d) can be found by averaging v_x:

$v_d = v_{ix}$ (average) $+ a_x \Delta t$ (average) $= eE/m \, \Delta t_{av}$

Zero, can you explain why?

$\Delta t_{av} = \tau$ - mean time between collisions

As a result we have: $v_d = e\tau E/m$ and $I = ne^2 \tau AE/m$

Conductivity and Resistivity

Current Density: $J = I/A = (ne^2\tau/m)E$

Let us introduce conductivity σ as

$\sigma = ne^2\tau/m$ (1)

When we have:

$J = \sigma E$ (2)

The equation (2) says:

- Current is caused by the electric field.
- The current density depends linearly on E.
- The current density also depends on conductivity (σ) related to some material properties, see Eq. (1).

Resistivity (ρ) is determined as an inverse of the conductivity:

$\rho = 1/\sigma = m/(\mathrm{ne}^2\tau)$

End of Lecture 11

Reading: Entire Chapter 28

HW 5 and monitor when HW6 will be uploaded