Quiz Week 6
ECE 656: Electronic Conduction In Semiconductors

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1) What are the special properties of a contact in the Landauer model?

   a) Strong inelastic scattering keeps them near equilibrium.
   b) Any electron incident upon the contact is completely absorbed (no reflections).
   c) Each contact is described by its own Fermi level.
   d) Contacts have a very large number of channels (modes) compared to the device.
   e) All of the above.

2) Which of the follow is true about the Landauer expression for current:
   $I = (2q/h)\int \mathcal{T}(E) M(E)(f_1 - f_2)dE$?

   a) It applies to electrons in the conduction band.
   b) It applies to electrons in the valence band.
   c) It applies to holes in the valence band.
   d) It applies to **both** <u>electrons</u> in the conduction band and <u>holes</u> in the valence band.
   e) It applies to both <u>electrons</u> in the conduction band and <u>electrons</u> in the valence band.

3) What are the units of the quantity, $h\langle v_x^+(E)\rangle D(E)/4$? The units of $D(E)$ are J^{-1}.

   a) Energy
   b) One over energy
   c) Ohms
   d) One over Ohms or Siemens.
   e) The quantity is unitless.

4) What is meant by the term "near-equilibrium" transport?

   a) The contacts stay very close to equilibrium.
   b) The Fermi level in the contact is close to its equilibrium value.
   c) The Fermi levels of the two contacts, f_1 and f_2, can be replaced by the equilibrium Fermi level.
   d) The difference in Fermi levels between the two contacts can be replaced by a first order Taylor series expansion of $f_1 - f_2$.
   e) The temperature of the two contacts is the same.

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5) Consider a small nano-device under bias with a steady-state current flowing. Which of the following is true?

a) One contact tries to fill states in the device and the other one tries to empty them.
b) Both contacts try to fill states in the device.
c) Both contacts try to empty states in the device.
d) All of the above.
e) None of the above.

6) Mathematically, the number of modes (channels) at energy, *E*, is proportional to what?

a) The density of states.
b) The velocity.
c) The density of states times velocity.
d) The density of states divided by velocity.
e) The deBroglie wavelength.

7) How is the transmission, $\mathcal{T}$, related to the mean-free-path for backscattering, λ, and the length of the resistor, L?

a) $\mathcal{T} = e^{-L/\lambda}$.
b) $\mathcal{T} = e^{+L/\lambda}$.
c) $\mathcal{T} = \lambda/L$.
d) $\mathcal{T} = L/\lambda$.
e) $\mathcal{T} = \lambda/(\lambda + L)$.

8) For parabolic band semiconductors, $M(E)$ is independent of energy (above the bottom of the conduction band) for which of the following cases?

a) 1D
b) 2D
c) 3D
d) 1D and 2D
e) 2D and 3D

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9) Under what conditions does the Landauer expression for current,

$$I = \frac{2q}{h} \int \mathcal{T}(E) M(E)(f_1 - f_2) dE$$, apply?

a) Near-equilibrium.
b) For near-ballistic transport conditions, $L << \lambda$.
c) For diffusive transport conditions, $L >> \lambda$
d) Far from equilibrium.
e) All of the above.

10) When should we NOT use the Landauer expression, $I = \frac{2q}{h} \int \mathcal{T}(E) M(E)(f_1 - f_2) dE$?

a) When quantum transport is important.
b) When semi-classical transport dominates.
c) When the temperatures of the two contacts are different.
d) When hole conduction dominates.
e) When it is necessary to spatially resolve quantities inside the device.

11) The electron current equation commonly used in semiconductor physics is written as $J_n = \sigma_n d(F_n/q)/dx$. To derive this from the Landauer approach, what assumptions are needed?

a) Near-equilibrium transport.
b) Constant temperature.
c) A conductor that is many mean-free-paths long.
d) Answers a) and c) above
e) Answers a) b), and c) above.

12) The drift-diffusion equation commonly used in semiconductor physics is written as $J_{nx} = nq\mu_n \mathcal{E}_x + qD_n dn/dx$. What assumption is **NOT needed** to derive this equation from the Landauer approach?

a) Near-equilibrium transport.
b) Constant temperature.
c) A conductor that is many mean-free-paths long.
d) Maxwell-Boltzmann statistics.
e) Steady-state conductions.

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13) Which of the following is correct about the conductivity of a 2D metal?

a) $\sigma_S = q^2 D_n(E_F) D_{2D}(E_F)$

b) $\sigma_S = q^2 D_{2D}(E_F)\dfrac{\upsilon^2(E_F)\tau(E_F)}{2}$

c) $\sigma_S = \dfrac{2q^2}{h} M_{2D}(E_F)\lambda(E_F)$

d) $\sigma_S = n_S q\left(\dfrac{q\tau(E_F)}{m^*}\right)$

e) All of the above are correct.

14) What is the quantity: $\dfrac{2q}{hn_S}\int \lambda(E) M_{2D}(E)\left(-\dfrac{\partial f_0}{\partial E}\right) dE$?

a) The conductivity of a 2D material.
b) The mobility of a 2D material.
c) The diffusion coefficient of a 2D material.
d) The average mean-free-path of a 2D material.
e) The resistivity of a 2D material.

15) How can we determine if a long resistor is operating in near-equilibrium conditions?

a) The voltage across the resistor must be less that $k_B T/q$.
b) The measured current is proportional to the applied voltage.
c) The magnitude of the electric field satisfies $\mathcal{E} \ll (k_B T/q)/\lambda_E$ where λ_E is the energy relaxation length.
d) a)and b) above.
e) a), b), and c) above.

16) The expression for the ballistic conductance, $G_{ball} = \dfrac{2q^2}{h} M(E_F)$ is valid when?

a) In the degenerate limit.
b) For 1D and 2D conductors.
c) For isothermal conditions.
d) For ballistic conductors
e) All of the above.

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17) In general, we can write the ballistic conductance as $G_{ball} = \frac{2q^2}{h}\langle M \rangle$. What is $\langle M \rangle$?

a) The number of channels.
b) The number of channels at the Fermi energy.
c) The average number of channels in the Fermi window.
d) The number of channels at the bottom of the conduction band.
e) The total number of channels in the Fermi window.

18) The expression for the resistance, $R = R_{\text{ball}}\left(1 + L/\lambda_0\right)$ is **not valid** under what conductions?

a) In the ballistic limit.
b) In the diffusive limit.
c) In between the ballistic and diffusive limits
d) When the mean-free-path depends on energy.
e) Under non-degenerate conductions.

19) For a ballistic resistor, the power dissipated is $P_D = IV = V^2/R$. Where is this power dissipated?

a) Uniformly within the resistor
b) Near the two ends of the resistor
c) In the contact with the most positive voltage
d) In the contact with the most negative voltage
e) In the two contacts.

20) For a ballistic resistor, with a voltage, *V*, applied across it, where does the voltage drop?

a) Uniformly within the resistor.
b) Near the two ends of the resistor.
c) In the contact with the most positive voltage.
d) In the contact with the most negative voltage.
e) In the two contacts.