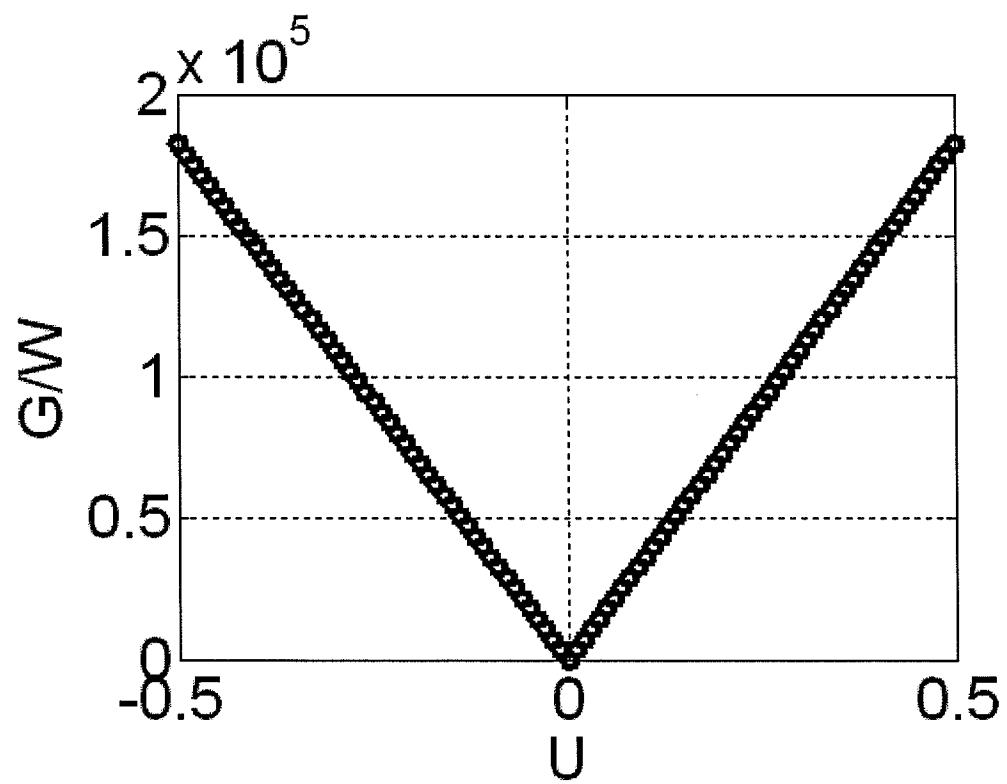
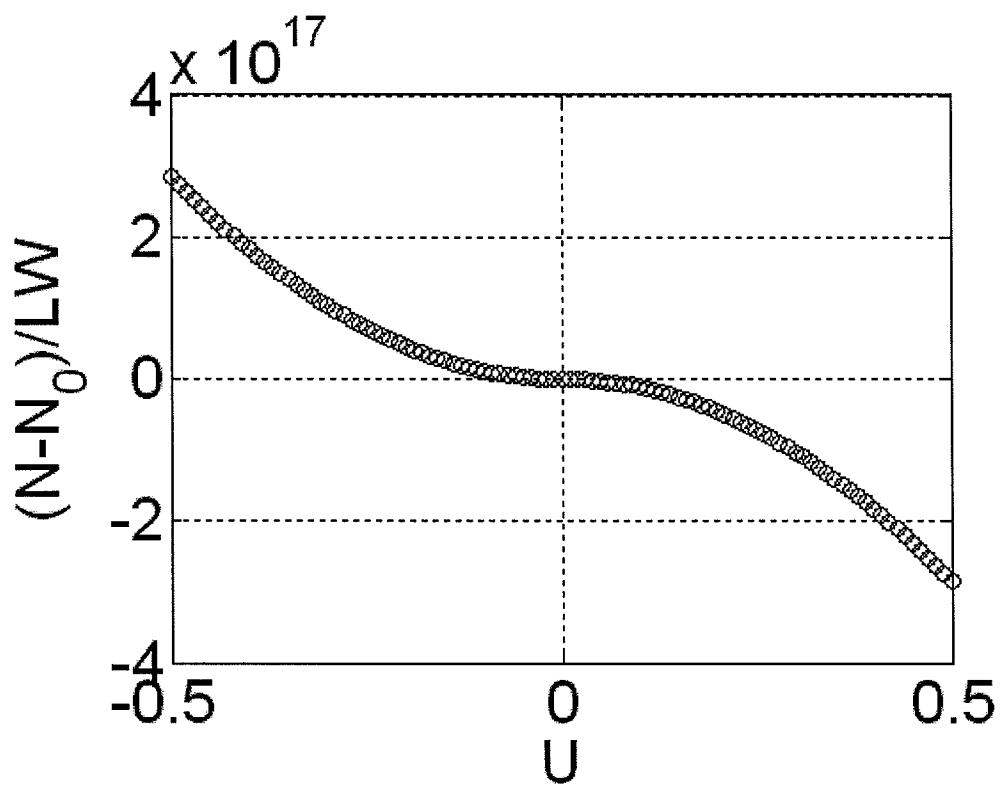


HW_3

Problem 1.

```
% Problem 1
clear all
hbar=1.06e-34;q=1.6e-19;vf=1e6;hv=hbar*vf/q;
%Parameters
kT=0.025;Ef=0;dE=0.001;E=[-1:dE:1];D=abs(E)/hv/hv;V=0.001;
ii=1;for U=-0.5:.01:+0.5
    mu1=Ef-U;mu2=Ef-U-V;
    f1=1./(1+exp((E-mu1)./kT));
    f2=1./(1+exp((E-mu2)./kT));
    f=1./(1+exp((E-Ef)./kT));
    N(ii)=sum(dE*D.*(f1+f2-f)./2);
    G(ii)=(q*q/hbar)*sum(dE*hv*D.*(f1-f2)./V);
    X(ii)=U;ii=ii+1;
end

NN= -0.5*X.*abs(X)./hv/hv;% analytical
GG=(q*q/hbar)*abs(X)./hv;% analytical
%%
hold on
figure(11)
h=plot(X,G,'b');
h=plot(X,GG,'bo');
set(h,'linewidth',[3.0])
set(gca,'Fontsize',[24])
grid on
figure(12)
h=plot(X,N,'b');
set(h,'linewidth',[3.0])
h=plot(X,NN,'bo');
set(gca,'Fontsize',[24])
grid on
```



Problem 1

$$D(E) = \frac{LW |E|}{(\hbar v_f)^2} \quad \Gamma_1 = \Gamma_2 \approx \frac{\hbar v_f}{L} \quad (L \ll \lambda)$$

$$N = \int_{-\infty}^{\infty} dE D(E-U) \frac{\Gamma_1 f_1 + \Gamma_2 f_2}{\Gamma_1 + \Gamma_2} \quad (\text{Low temperature})$$

$$= \int_{-\infty}^{\infty} dE D(E) \frac{1}{2} (f_1(E+U) + f_2(E+U)) \quad (\mu_1 \approx \mu_2)$$

$$\approx \int_{-\infty}^{\infty} dE D(E) f_1(E+U) \approx \int_{-\infty}^{-U} dE D(E)$$

$$N_0 = \int_{-\infty}^{\infty} dE D(E) f_1(E) \approx \int_{-\infty}^0 dE D(E)$$

$$\therefore N - N_0 = \int_{-\infty}^{-U} dE D(E) - \int_{-\infty}^0 dE D(E) =$$

If $U > 0$

$$\frac{N - N_0}{LW} = - \int_{-U}^0 dE \frac{|E|}{(\hbar v_f)^2} = \int_{-U}^0 dE \frac{E}{(\hbar v_f)^2} = - \frac{U^2}{2(\hbar v_f)^2}$$

If $U < 0$

$$\frac{N - N_0}{LW} = \int_0^{-U} dE \frac{|E|}{(\hbar v_f)^2} = \int_0^{-U} dE \frac{E}{(\hbar v_f)^2} = \frac{U^2}{2(\hbar v_f)^2}$$

$$G = \frac{q^2}{k} \int_{-\infty}^{\infty} dE D(E-U) \frac{f_1 f_2}{f_1 + f_2} \left(-\frac{\partial f_1}{\partial E} \right)$$

$\left(-\frac{\partial f_1}{\partial E} \right)$ is already a f function. But I'll try the other way

$$f_1(E) = \frac{1}{1 + \exp\left(\frac{E - \mu_1}{kT}\right)}, \quad \frac{\partial f_1}{\partial E} = -\frac{\partial f_1}{\partial \mu_1}$$

$$G = \frac{q^2}{k} \int_{-\infty}^{\infty} dE D(E-U) \frac{\hbar v_f}{2L} \left(\frac{\partial f_1}{\partial \mu_1} \right)$$

$$\begin{aligned} & \approx \frac{q^2}{k} \int_{-\infty}^{\infty} dE D(E-U) \frac{\hbar v_f}{2L} \frac{f_1 - f_2}{\mu_1 - \mu_2} & \mu_1 = 0 \\ & \approx \frac{q^2}{k} \int_{-gV_D}^0 dE \frac{\Delta W |E-U|}{(\hbar v_f)^2} \frac{(\cancel{\hbar v_f})}{2\Delta} \frac{1}{gV_D} & \mu_2 = -gV_D \\ & \approx \frac{q^2}{k} \frac{|U| W}{2(\hbar v_f)} \frac{2V_D}{gV_D} & |E-U| \approx |U| \end{aligned}$$

$$= \frac{q^2}{k} \frac{|U| W}{2(\hbar v_f)} \frac{2V_D}{gV_D}$$

$$\therefore \frac{G}{W} = \frac{q^2}{k} \frac{|U|}{2(\hbar v_f)}$$

Problem 2.

Textbook

Problem3.

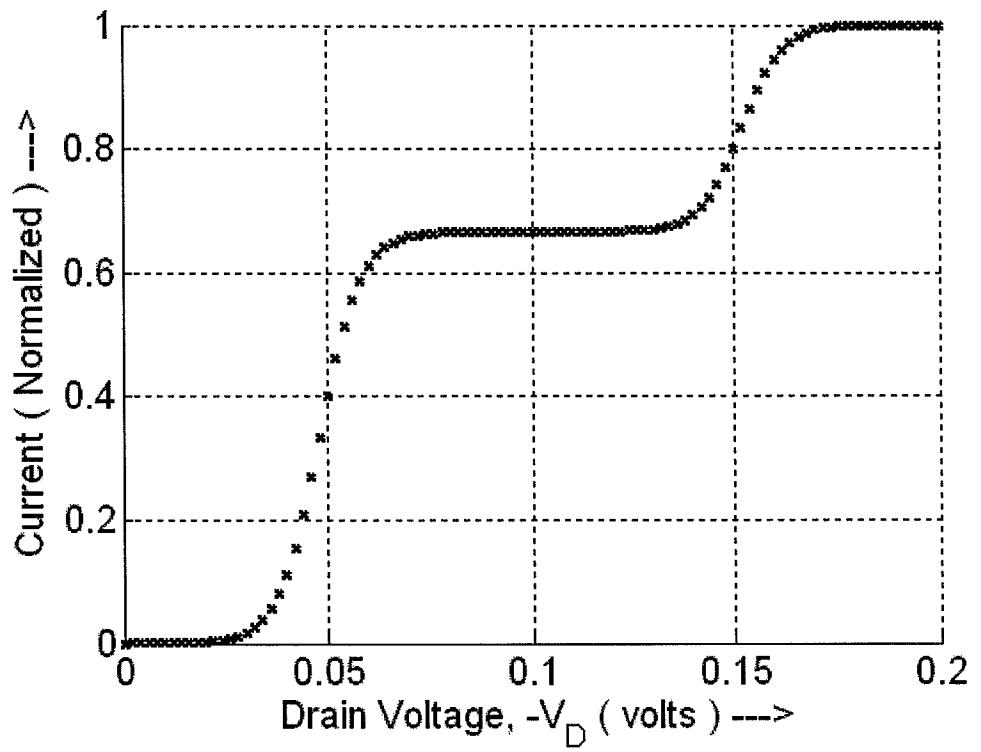
```
clear all
% close all
%Constants (all MKS, except energy which is in eV)
hbar=1.055e-34;q=1.602e-19;l0=q*q/hbar;
l0=1;

%Parameters
U0=0.1;% U0 is 0.25 for part(a), 0.025 for part (b)
kT=0.005;mu=0;ep=0.05;
g1=0.005;g2=0.005;g=g1+g2;
% g1=1;g2=1;g=g1+g2;
alphag=0;alphad=0;

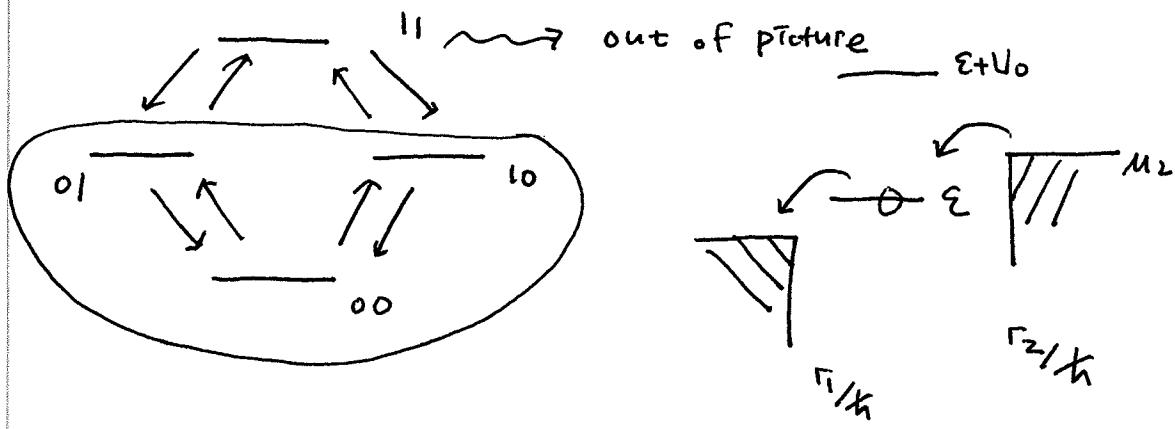
%Bias
IV=101;VV=linspace(0,0.2,IV);
for iV=1:IV
    Vg=0;Vd=-VV(iV);
    mu1=mu;mu2=mu1-Vd;UL=-(alphag*Vg)-(alphad*Vd);
    f1=1/(1+exp((ep+UL-0*(U0/2)-mu1)/kT));f2=1/(1+exp((ep+UL-0*(U0/2)-mu2)/kT));
    f1U=1/(1+exp((ep+UL+2*(U0/2)-mu1)/kT));f2U=1/(1+exp((ep+UL+2*(U0/2)-mu2)/kT));

    P1=((g1*f1)+(g2*f2))/(0e-6+(g1*(1-f1))+(g2*(1-f2)));
    P2=P1*((g1*f1U)+(g2*f2U))/(0e-6+(g1*(1-f1U))+(g2*(1-f2U)));
    P0=1/(1+P1+P1+P2);P1=P1*P0;P2=P2*P0;

    NN(iV)=2*(P1+P2);
    I1(iV)=2*I0*((P0*g1*f1)-(P1*g1*(1-f1))+(P1*g1*f1U)-(P2*g1*(1-f1U)));
    I2(iV)=2*I0*((P0*g2*f2)-(P1*g2*(1-f2))+(P1*g2*f2U)-(P2*g2*(1-f2U)));
end
P0
P1
P2
%%
hold on
h=plot(VV,I2/max(I2),'bx');
% plot(VV,I,'bx');
set(h,'linewidth',[2.0])
set(gca,'FontSize',[15])
grid on
xlabel(' Drain Voltage, -V_D ( volts ) --->')
ylabel(' Current ( Normalized ) ----> ')
```



Problem 3.



$$f_2(\varepsilon) = 1, \quad f_1(\varepsilon) = 0$$

$$P_{01} + P_{10} + P_{00} = 1, \quad P_{01} = P_{10} \quad \rightarrow \quad 2P_{01} + P_{00} = 1$$

$$\Gamma_2 P_{00} = \Gamma_1 P_{01} \quad (\text{Steady-state condition})$$

$$\frac{I}{q\varepsilon} = 2 \frac{\Gamma_2}{k} P_{00} = 2 \frac{\Gamma_2}{k} \frac{\Gamma_1}{2\Gamma_2 + \Gamma_1} = \frac{1}{k} \frac{2\Gamma_1\Gamma_2}{\Gamma_1 + 2\Gamma_2}$$

$$I = \frac{q}{k} \frac{2\Gamma_1\Gamma_2}{\Gamma_1 + 2\Gamma_2}$$