Problem 7

```
clc
clear
close all

T = 300;
q = 1.602e-19; % C
KB_J = 1.381e-23;
KB_eV = 8.617e-5;
h = 6.626e-34;
h_bar = h / (2*pi);
m_e = 9.109e-31;
m_gamma = 0.067 * m_e;
p = 5360;
v_s = 5220;
D_acoustic = 7.01 * q;
e_s = 12.9; % static dielectric constant
e_inf = 10.9; % high-frequency dielectric constant
e_0 = 8.854e-12; % vacuum permittivity in F/m
e_0_cm = e_0 / 100; % vacuum permittivity in F/cm
E_phonon = 35.36e-3 * q; % energy of a phonon in GaAs in J
w_LO = E_phonon / h_bar; % rad/s for phonon in GaAs
N = 1e17; % concentration (cm^-3)
Z = 1; % charge state of GaAs

% Energy in eV
E = linspace(0, 5 * KB_eV * T, 100);      % eV
E_J = E * q;                              % Convert to joules

% Compute everything
D = DOS(E_J, m_gamma, h_bar);             % Use E in joules
f0 = exp(-(E + 0.042) / (KB_eV * T));     % All in eV

tau0_acoustic = (2 * pi * p * v_s^2 * h_bar^4) / ...
    (D_acoustic^2 * (2 * m_gamma)^1.5 * (KB_J * T)^1.5); % seconds
S_acoustic = -0.5;
tau_f_acoustic = tau0_acoustic * (4 / (3 * sqrt(pi))) * gamma(S_acoustic + 2.5); %
seconds
mu_acoustic = tau_f_acoustic * q / m_gamma
```

```
mu_acoustic =
15.6263
```

```
fprintf('Mobility Limtied by Acoustic Phonon Scattering: %f m^2/Vs', mu_acoustic);
```

```
Mobility Limtied by Acoustic Phonon Scattering: 15.626295 m^2/Vs
```

```
tau0_ionized = 2^4.5 * (pi * e_0^2 * e_s^2 * sqrt(m_gamma)) / ...
    (N * Z^2 * q^4);
```

```
S_ionized = 1.5;
tau_f_ionized = tau0_ionized * (4 / (3 * sqrt(pi))) * gamma(S_ionized  + 2.5); %
seconds
mu_ionized = tau_f_ionized * q / m_gamma;
fprintf('Mobility Limtied by Acoustic Phonon Scattering: %f m^2/Vs', mu_ionized);
```

```
Mobility Limtied by Acoustic Phonon Scattering: 41209568971668216156939347994087522304.000000 m^2/Vs
```

```
gamma_pop = pop_scatter(E_J, m_gamma, h_bar, w_LO, E_phonon, KB_J, q, e_inf, e_s,
e_0, T);
tau = 1 ./ gamma_pop;
numerator = trapz(E, E .* tau .* D .* f0);
denominator = trapz(E, E .* D .* f0);
avg_tau = numerator / denominator;
mu_pop = q * avg_tau / m_gamma;
fprintf('Mobility Limtied by Acoustic Phonon Scattering: %f m^2/Vs', mu_pop);
```

```
Mobility Limtied by Acoustic Phonon Scattering: 0.551842 m^2/Vs
```

c)

```
mu_total = (1/mu_pop) + (1/mu_ionized) + (1/mu_acoustic);
mu_total = (1/mu_total) * 1e4; % in cm^2/Vs
fprintf('Total Mobility (Matthiessens Rule: %f cm^2/Vs', mu_total);
```

```
Total Mobility (Matthiessens Rule: 5330.181315 cm^2/Vs
```

```
conductivity = q * N * mu_total * 100; % S/m
fprintf('Conductivity: %f S/m', conductivity);
```

```
Conductivity: 8538.950467 S/m
```

d)

```
gamma_acoustic = ac_scatter(E_J, m_gamma, h_bar, p, v_s, D_acoustic, KB_J, T);
gamma_ionized = ion_imp(E_J, N, Z, q, h_bar, e_0, e_s, m_gamma, T, KB_J);
total_gamma = gamma_ionized + gamma_acoustic + gamma_pop;
total_gamma(1) = total_gamma(2);
tau_total = 1 ./ total_gamma;
numerator = trapz(E, E .* tau_total .* D .* f0);
denominator = trapz(E, E .* D .* f0);
avg_tau = numerator / denominator;
mu_total = 1e4 * q * avg_tau / m_gamma;
fprintf('Total Mobility (without Matthiessens Rule: %f cm^2/Vs', mu_total);
```

```
Total Mobility (without Matthiessens Rule: 1295.172484 cm^2/Vs
```

Polar-Optical-Phonon Scattering

```
function pop_scatter = pop_emit(E, m, h_bar, w_0, E_phonon, KB_J, q, e_inf, e_s,
e_0, T)
    pop_scatter = zeros(1, length(E));
    for i = 1:length(E)
```

```
        x = h_bar * w_0 / E(i);
        C = ((q^2 * w_0) / (8 * pi * e_0)) * sqrt(2 * m / (h_bar^2)) * ...
            ((1 / e_inf) - (1 / e_s)) * (1 / sqrt(E(i)));
        N_0 = 1 / (exp(E_phonon / (KB_J * T)) - 1);

        if E(i) > (h_bar * w_0)
            pop_scatter(i) = C * ((N_0 + 1) * log(abs((1 + sqrt(1 - x)) / (1 -
sqrt(1 - x)))));
        end
    end
end

function pop_scatter = pop_abs(E, m, h_bar, w_0, E_phonon, KB_J, q, e_inf, e_s,
e_0, T)
    pop_scatter = zeros(1, length(E));
    for i = 1:length(E)
        x = h_bar * w_0 / E(i);
        C = ((q^2 * w_0) / (8 * pi * e_0)) * sqrt(2 * m / (h_bar^2)) * ...
            ((1 / e_inf) - (1 / e_s)) * (1 / sqrt(E(i)));
        N_0 = 1 / (exp(E_phonon / (KB_J * T)) - 1);

        pop_scatter(i) = C * (N_0 * log(abs((1 + sqrt(1 + x)) / (-1 + sqrt(1 +
x)))));
    end
end

function total_pop = pop_scatter(E, m, h_bar, w_0, E_phonon, KB_J, q, e_inf, e_s,
e_0, T)
    abs = pop_abs(E, m, h_bar, w_0, E_phonon, KB_J, q, e_inf, e_s, e_0, T);
    emit = pop_emit(E, m, h_bar, w_0, E_phonon, KB_J, q, e_inf, e_s, e_0, T);
    total_pop = abs + emit;
    total_pop(1) = total_pop(2);
end
```

DOS

```
function g_DOS = DOS(E, m, h_bar)
    g_DOS = zeros(1, length(E));
    for i = 1:length(E)
        if E(i) > 0
            g_DOS(i) = (sqrt(E(i)) / (2 * (pi^2))) * (2 * m / (h_bar ^ 2)) ^ 1.5;
        else
            g_DOS(i) = 0;
        end
    end
end
```

Acoustic

```
function acoustic = ac_scatter(E, m, h_bar, p, v_s, D, KB_J, T)
```

```
    acoustic = (D^2 * KB_J * T) / (2 * pi * h_bar * p * v_s^2) * ...
        ((2 * m) / (h_bar ^ 2)) ^ 1.5 * sqrt(E);
end
```

Ionized Impurities

```
function ion_impurities = ion_imp(E, n, Z, q, h_bar, e_0, e_s, m, T, KB_J)
    k = sqrt(2 * m * E / h_bar^2);
    ion_impurities = zeros(1, length(k));
    Ld = sqrt((e_0 * e_s * T * KB_J) / (n * q ^ 2));

    X = (n * Z^2 * q^4 * Ld^4 * m) / (pi * h_bar^3 * e_0^2 * e_s^2);

    for j = 1:length(k)
        ion_impurities(j) = X * (k(j) ./ (4 * k(j)^2 * Ld^2 + 1));
    end
end
```