Photoluminescence: data analysis

Load data

```
clear;
RhoData = ParsePLdata('rhodamine', 'photonE');  % Rhodamine

Temps = 10:10:290;
RubyData = cell(numel(Temps),1);    % Ruby
for it = 1:numel(Temps)
    RubyData{it} = ParsePLdata('ruby', Temps(it), 'photonE');
end

RubyRoomData = ParsePLdata('rubyRtemp', 'photonE');
```

Define loss function for fitting

```
function loss = peak_sensitive_loss(yhat, y)
    delta = max(y) * 1e-3;
    loss = mean(((yhat - y).^2) ./ (abs(y) + delta) .* (y>300 | (y<300 &
yhat>300)));
end
loss_func = @peak_sensitive_loss;
```

Define R-square function for fitting

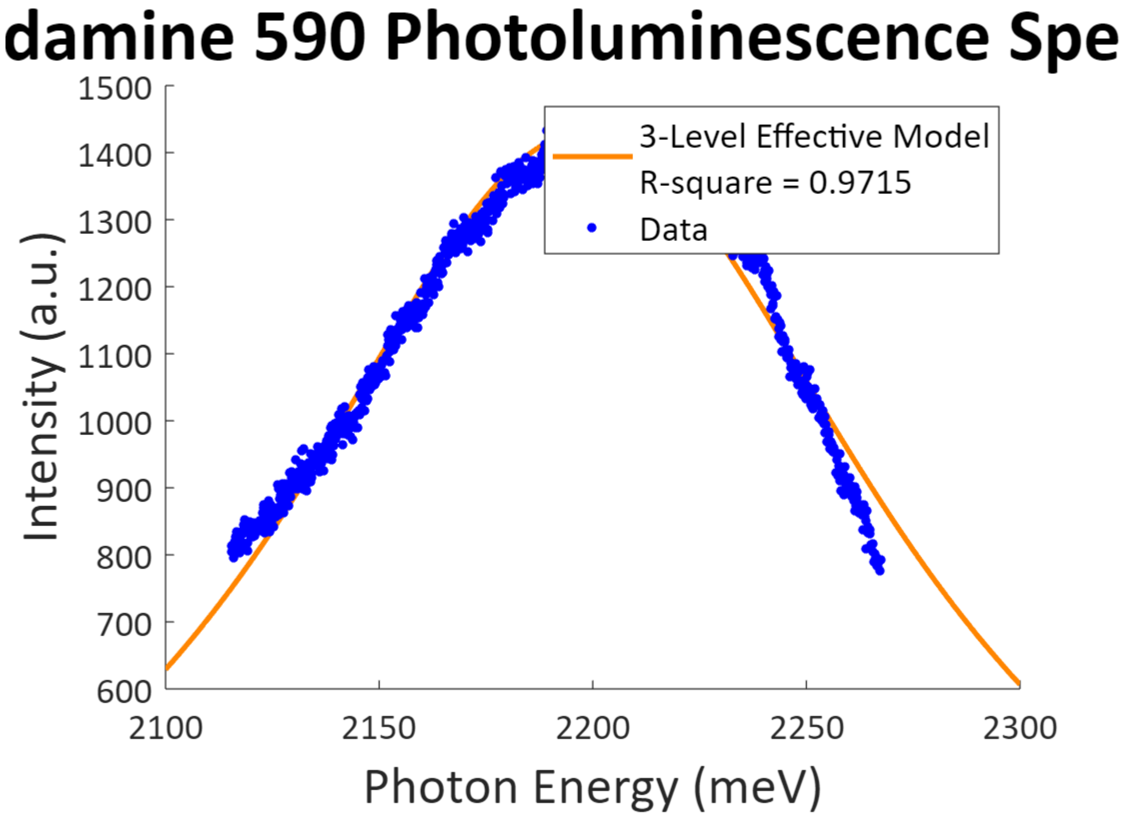
```
function Rsq = Rsqcal(fitted, experimental)
%RSQCAL   Compute coefficient of determination (R^2)
%   Rsq = Rsqcal(fitted, experimental) returns the R^2 value between
%   the predicted data in fitted and the observed data in experimental.
%
%   R^2 = 1 - SS_res / SS_tot
%     where SS_res = sum((y_obs - y_fit).^2)
%           SS_tot = sum((y_obs - mean(y_obs)).^2)
%
%   Inputs must be vectors of the same length.

    % Ensure inputs are column vectors
    f = fitted(:);
    y = experimental(:);

    % Check sizes
    if numel(f) ~= numel(y)
        error('Rsqcal:InputSizeMismatch', ...
              '''fitted'' and ''experimental'' must have the same number of
elements.');
    end
```

```
    % Total sum of squares
    ymean = mean(y);
    SS_tot = sum((y - ymean).^2);

    if SS_tot == 0
        % all y are identical → variance zero → R^2 undefined
        warning('Rsqcal:ZeroVariance', ...
                'All experimental values are identical; R^2 is undefined. Returning
NaN.');
        Rsq = NaN;
        return;
    end

    % Residual sum of squares
    SS_res = sum((y - f).^2);

    % Coefficient of determination
    Rsq = 1 - SS_res/SS_tot;
end
```

Fit & Plot Rhodamine Data to 3-level effective model (single Lorentzian)

```
% photon energy range
Erange = [2100, 2300];
Energy = linspace(Erange(1), Erange(2), 1000);

% lower and upper bounds of fitting parameters
LowerBound = [1e3, -5, 2150];
UpperBound = [1e6, 3, 2250];

% choose data near the peaks
Idx = RhoData(:,1) > Erange(1) & RhoData(:,1) < Erange(2);
E_data = RhoData(Idx,1);
I_data = RhoData(Idx,2);

% make parameter bounds and loss function into a single struct variable
options.lb = LowerBound;
options.ub = UpperBound;
options.loss_type = loss_func;

% define fitting curve
FitModel = @(Params, Energies) Spec_3lev(Params(1), power(10, Params(2)),
Params(3), Energies);

% iterate to find best fit
best_loss = Inf;
for it = 1:3
    options.rng_seed = it;          % Try different seeds
    Params0 = rand(1,3) .* (UpperBound - LowerBound) + LowerBound;      % try
different initial parameters
```

```
    [params_i, loss_hist_i] = de_curve_fit(FitModel, E_data, I_data, Params0, 
options);     % differential evolution fitting
    if loss_hist_i(end) < best_loss
        best_loss = loss_hist_i(end);
        FitParams = params_i;
        loss_history = loss_hist_i;
    end
end

I0 = FitParams(1);
Linewidth = power(10, FitParams(2));
Ecen = FitParams(3);

% plot
figure;
hold on;
I_fit = Spec_3lev(I0, Linewidth, Ecen, Energy);
I_fit_sameidx = Spec_3lev(I0, Linewidth, Ecen, E_data);
Rsq = Rsqcal(I_fit_sameidx, I_data);
plot(Energy, I_fit, 'color', '#FF8500', 'LineWidth', 2);
plot(E_data, I_data, 'o', 'MarkerEdgeColor', 'blue', 'MarkerFaceColor', 'blue', 
'MarkerSize', 3);
ax = gca;
ax.FontSize = 14;
ax.FontName = 'Calibri';
xlabel('Photon Energy (meV)', 'FontName', 'Calibri', 'FontSize', 20);
ylabel('Intensity (a.u.)', 'FontName', 'Calibri', 'FontSize', 20);
title('Rhodamine 590 Photoluminescence Spectrum', 'FontName', 'Calibri', 
'FontSize', 28);
lg = legend({sprintf('3-Level Effective Model\nR-square = %.4f', Rsq),'Data'}, 
'Location','northeast', 'FontName', 'Calibri', 'FontSize', 14);
```




```
pos = lg.Position;
% choose a point just below the legend box
x_txt = 0.900;
y_txt = 0.800;        % tweak the 0.05 to move it closer/further

% show fit parameters
disp(['Loss = ', sprintf('%.4g', best_loss)]);
```

```
Loss = 1.151
```

```
disp(['I0 = ', sprintf('%.4g', I0)]);
```

```
I0 = 1.247e+05
```

```
disp(['Linewidth = ', sprintf('%.4g', Linewidth(1))]);
```

```
Linewidth = 174.4
```

```
disp(['Ecen = ', sprintf('%.4g', Ecen)]);
```

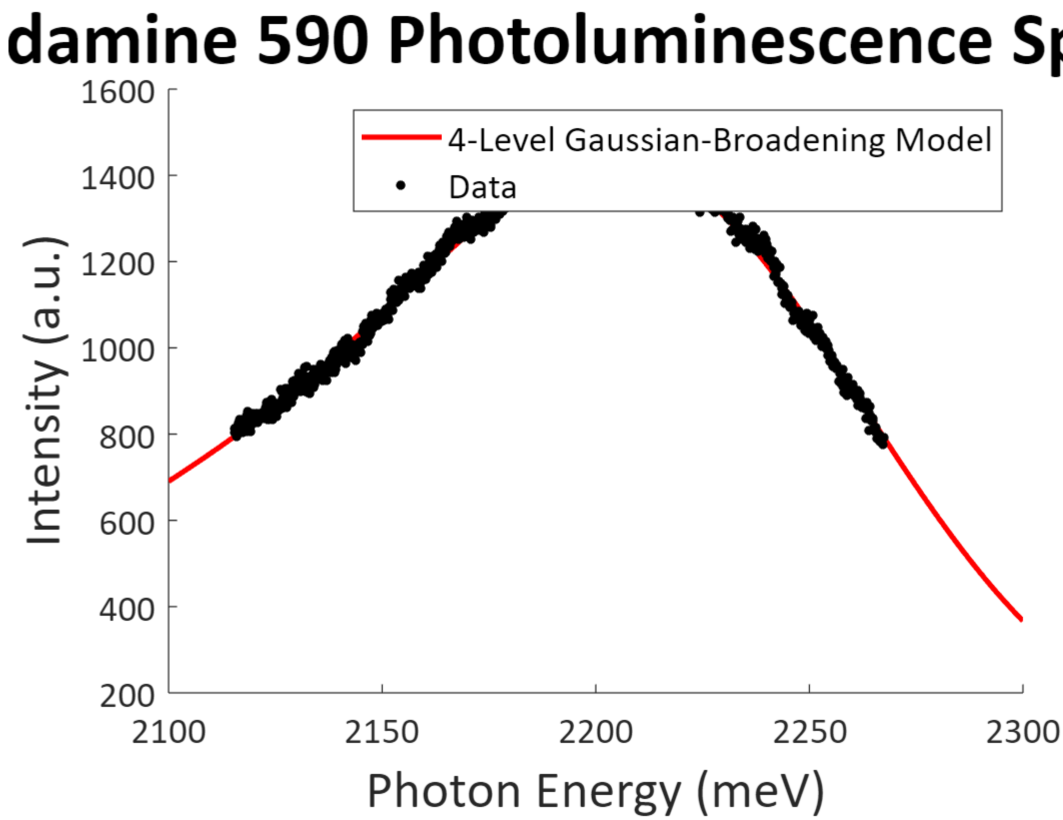
```
Ecen = 2198
```

Fit & Plot Rhodamine Data to Double Gaussian Model

```
% broaden option
Broaden = 'Gauss';

% photon energy range
```

```
Erange = [2100, 2300];
Energy = linspace(Erange(1), Erange(2), 1000);

% lower and upper bounds of fitting parameters
LowerBound = [10, 0, -5, -5, 1e-2, 2150];
UpperBound = [1e6, 10, 3, 3, 1e2, 2250];

% fit data
T = 290;    % temperature

% choose data near the peaks
Idx = RhoData(:,1) > Erange(1) & RhoData(:,1) < Erange(2);
E_data = RhoData(Idx,1);
I_data = RhoData(Idx,2);

% make parameter bounds and loss function into a single struct variable
options.lb = LowerBound;
options.ub = UpperBound;
options.loss_type = loss_func;

% define fitting curve
FitModel = @(Params, Energies) Spec_4lev(Params(1), Params(2), [power(10,
Params(3)), power(10, Params(4))], Params(5), Params(6), T, Energies, 'Broaden',
Broaden);

% iterate to find best fit
best_loss = Inf;
for it = 1:3
    options.rng_seed = it;          % Try different seeds
    Params0 = rand(1,6) .* (UpperBound - LowerBound) + LowerBound;      % try
different initial parameters
    [params_i, loss_hist_i] = de_curve_fit(FitModel, E_data, I_data, Params0,
options);     % differential evolution fitting
    if loss_hist_i(end) < best_loss
        best_loss = loss_hist_i(end);
        FitParams = params_i;
        loss_history = loss_hist_i;
    end
end

% show fit parameters
I0 = FitParams(1);
TransAmpR = FitParams(2);
Linewidth = [power(10, FitParams(3)), power(10, FitParams(4))];
Delta = FitParams(5);
E1 = FitParams(6);

% plot
figure;
hold on;
```

```
I_fit = Spec_4lev(I0, TransAmpR, Linewidth, Delta, E1, T, Energy, 'Broaden',
Broaden);
plot(Energy, I_fit, 'color', 'red', 'LineWidth', 2);
plot(E_data, I_data, 'o', 'MarkerEdgeColor', 'black', 'MarkerFaceColor', 'black',
'MarkerSize', 3);
ax = gca;
ax.FontSize = 14;
ax.FontName = 'Calibri';
xlabel('Photon Energy (meV)', 'FontName', 'Calibri', 'FontSize', 20);
ylabel('Intensity (a.u.)', 'FontName', 'Calibri', 'FontSize', 20);
title('Rhodamine 590 Photoluminescence Spectrum', 'FontName', 'Calibri',
'FontSize', 28);
legend({'4-Level Gaussian-Broadening Model','Data'}, 'Location','northeast',
'FontName', 'Calibri', 'FontSize', 14);

hold off;
```




```
% show fitted parameters
disp(['Temperature = ', sprintf('%d', T), ' K']);
```

```
Temperature = 290 K
```

```
disp(['Loss = ', sprintf('%.4g', best_loss)]);
```

```
Loss = 0.2881
```

```
disp(['I0 = ', sprintf('%.4g', I0)]);
```

```
I0 = 1.678e+05
```

```
disp(['d_{20}/d_{10} = ', sprintf('%.4g', TransAmpR)]);
```

```
d_{20}/d_{10} = 2.938
```

```
disp(['Linewidths = [', sprintf('%.4g', Linewidth(1)), ', ', sprintf('%.4g',
Linewidth(2)) ']']);
```

```
Linewidths = [88.43, 48.27]
```

```
disp(['Delta = ', sprintf('%.4g', Delta)]);
```

```
Delta = 66.51
```

```
disp(['E1 = ', sprintf('%.4g', E1)]);
```

```
E1 = 2150
```

Fit Ruby Data to 4-Level Effective Model (T = 10K - 290K, double Lorentzian)

```
% photon energy range
Erange = [1785, 1795];
Energy = linspace(Erange(1), Erange(2), 1000);

% lower and upper bounds of fitting parameters
LowerBound = [2000, 0.5, -0.9, -0.8, 3.5, 1785];
UpperBound = [3400, 3, -0.2, -0.35, 4, 1795];

% variables to store fit parameters
I0 = zeros(29,1);
TransAmpR = zeros(29,1);
Linewidth = zeros(29,2);
Delta = zeros(29,1);
E1 = zeros(29,1);

% fit all 29 data
for Dnum = 1:29

    T = 10*Dnum;    % temperature

    % choose data near the peaks
    Idx = RubyData{Dnum}(:,1) > Erange(1) & RubyData{Dnum}(:,1) < Erange(2);
    E_data = RubyData{Dnum}(Idx,1);
    I_data = RubyData{Dnum}(Idx,2);

    % make parameter bounds and loss function into a single struct variable
    options.lb = LowerBound;
    options.ub = UpperBound;
    options.loss_type = loss_func;

    % define fitting curve
```

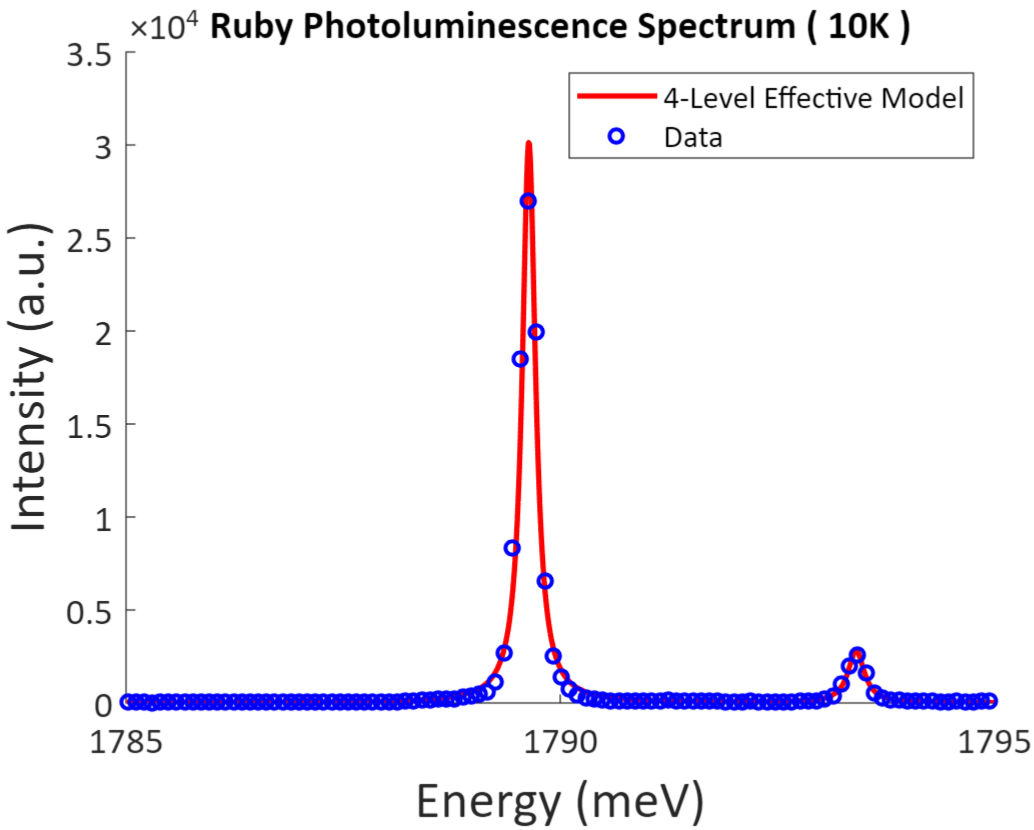
```
    FitModel = @(Params, Energies) Spec_4lev(Params(1), Params(2), [power(10,
Params(3)), power(10, Params(4))], Params(5), Params(6), T, Energies);

    % iterate to find best fit
    best_loss = Inf;
    for it = 1:3
        options.rng_seed = it;          % Try different seeds
        Params0 = rand(1,6) .* (UpperBound - LowerBound) + LowerBound;      % try
different initial parameters
        [params_i, loss_hist_i] = de_curve_fit(FitModel, E_data, I_data, Params0,
options);     % differential evolution fitting
        if loss_hist_i(end) < best_loss
            best_loss = loss_hist_i(end);
            FitParams = params_i;
            loss_history = loss_hist_i;
        end
    end

    I0(Dnum) = FitParams(1);
    TransAmpR(Dnum) = FitParams(2);
    Linewidth(Dnum,:) = [power(10, FitParams(3)), power(10, FitParams(4))];
    Delta(Dnum) = FitParams(5);
    E1(Dnum) = FitParams(6);

    % show message
    disptime(['Data #', sprintf('%d', Dnum), ' | loss = ', sprintf('%.4g',
best_loss)]);

end
```

```
25-06-10 08:38:56 | Data #1 | loss = 49.98
25-06-10 08:39:01 | Data #2 | loss = 43.87
25-06-10 08:39:04 | Data #3 | loss = 39.89
25-06-10 08:39:08 | Data #4 | loss = 39.45
25-06-10 08:39:12 | Data #5 | loss = 30.66
25-06-10 08:39:16 | Data #6 | loss = 27.68
25-06-10 08:39:19 | Data #7 | loss = 25.03
25-06-10 08:39:23 | Data #8 | loss = 20.75
25-06-10 08:39:27 | Data #9 | loss = 20.75
25-06-10 08:39:30 | Data #10 | loss = 13.79
25-06-10 08:39:34 | Data #11 | loss = 16.85
25-06-10 08:39:38 | Data #12 | loss = 18.88
25-06-10 08:39:41 | Data #13 | loss = 17.28
25-06-10 08:39:45 | Data #14 | loss = 17.82
25-06-10 08:39:48 | Data #15 | loss = 17.82
25-06-10 08:39:51 | Data #16 | loss = 20.43
25-06-10 08:39:54 | Data #17 | loss = 23.6
25-06-10 08:39:58 | Data #18 | loss = 21.36
25-06-10 08:40:01 | Data #19 | loss = 7.19
25-06-10 08:40:04 | Data #20 | loss = 21.98
25-06-10 08:40:08 | Data #21 | loss = 20.05
25-06-10 08:40:11 | Data #22 | loss = 25.05
25-06-10 08:40:14 | Data #23 | loss = 8.6
25-06-10 08:40:17 | Data #24 | loss = 7.995
25-06-10 08:40:21 | Data #25 | loss = 26.73
25-06-10 08:40:24 | Data #26 | loss = 22.84
```

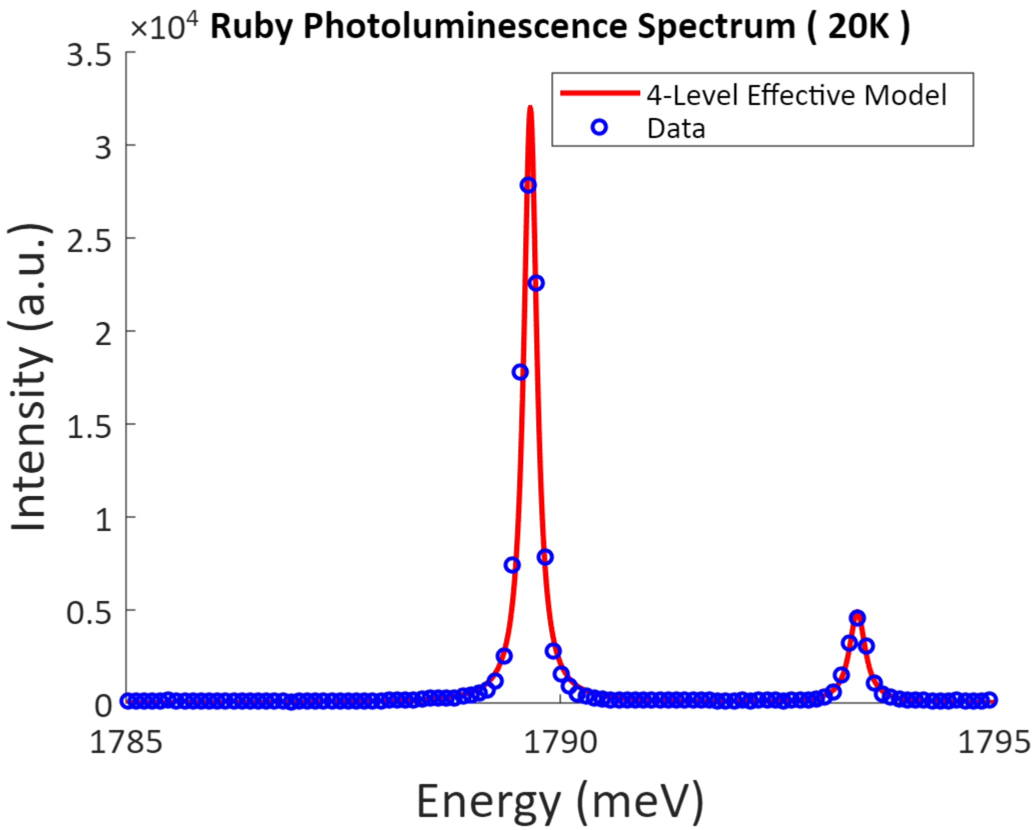
```
25-06-10 08:40:28 | Data #27 | loss = 27.09
25-06-10 08:40:31 | Data #28 | loss = 2.582
25-06-10 08:40:35 | Data #29 | loss = 26.43
```

Plot Ruby Data with Fit Curve

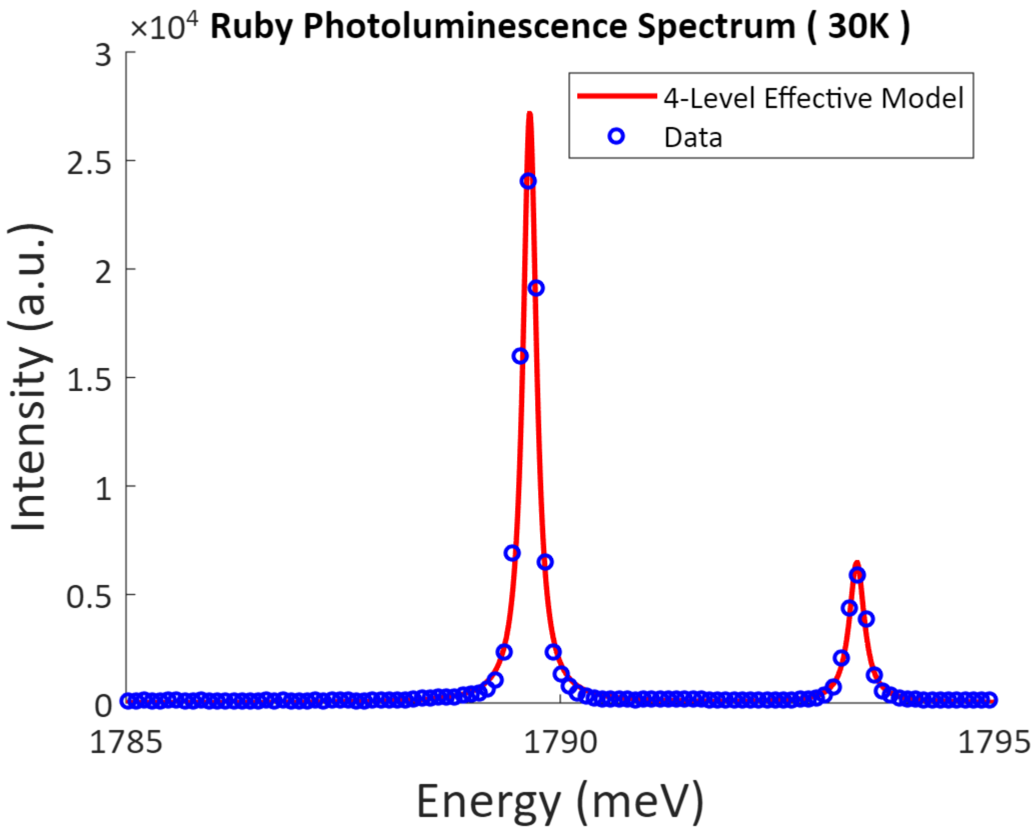
```
for Dnum = 1:29

    T = 10*Dnum;    % temperature

    % choose data near the peaks
    Idx = RubyData{Dnum}(:,1) > Erange(1) & RubyData{Dnum}(:,1) < Erange(2);
    E_data = RubyData{Dnum}(Idx,1);
    I_data = RubyData{Dnum}(Idx,2);

    % plot
    figure;
    hold on;
    I_fit = Spec_4lev(I0(Dnum), TransAmpR(Dnum), Linewidth(Dnum,:), Delta(Dnum),
E1(Dnum), T, Energy);
    plot(Energy, I_fit, 'color', 'red', 'LineWidth', 2);
    plot(E_data, I_data, 'o', 'color', 'blue', 'Markersize', 5, 'LineWidth', 1.5);
    ax = gca;
    ax.FontSize = 14;
    ax.FontName = 'Calibri';
    xlabel('Energy (meV)', 'FontName', 'Calibri', 'FontSize', 20);
    ylabel('Intensity (a.u.)', 'FontName', 'Calibri', 'FontSize', 20);
    title(['Ruby Photoluminescence Spectrum ( ', sprintf('%d', T), 'K )'],
'FontName', 'Calibri', 'FontSize', 15);
    legend({'4-Level Effective Model', 'Data'}, 'Location','northeast', 'FontName',
'Calibri', 'FontSize', 12);
    hold off;

    % show fit parameters
    disp('Fit Parameters :')
    disp(['T = ', sprintf('%d', T), ' K']);
    disp(['I0 = ', sprintf('%.4g', I0(Dnum))]);
    disp(['d_{20}/d_{10} = ', sprintf('%.4g', TransAmpR(Dnum))]);
    disp(['Linewidths = [', sprintf('%.4g', Linewidth(Dnum,1)), ', ',
sprintf('%.4g', Linewidth(Dnum,2)) ']']);
    disp(['Delta = ', sprintf('%.4g', Delta(Dnum))]);
    disp(['E1 = ', sprintf('%.4g', E1(Dnum))]);
end
```



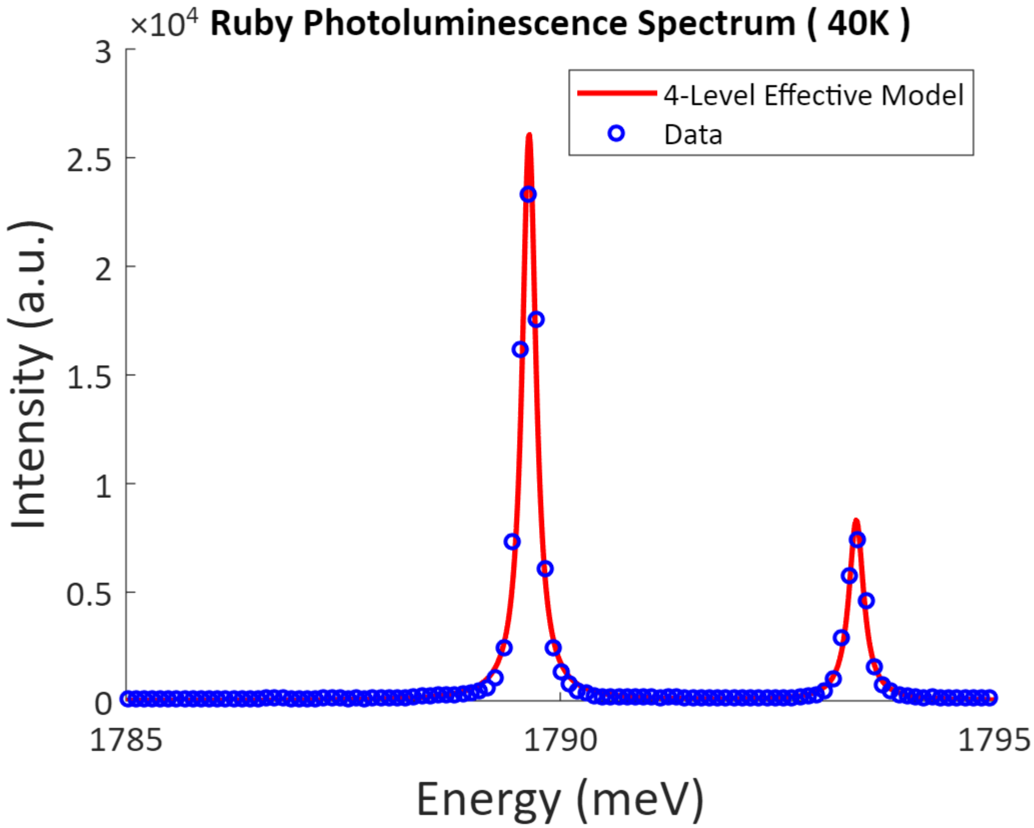

```
Fit Parameters :
T = 10 K
I0 = 2800
d_{20}/d_{10} = 2.994
Linewidths = [0.1855, 0.2272]
Delta = 3.768
E1 = 1790
```



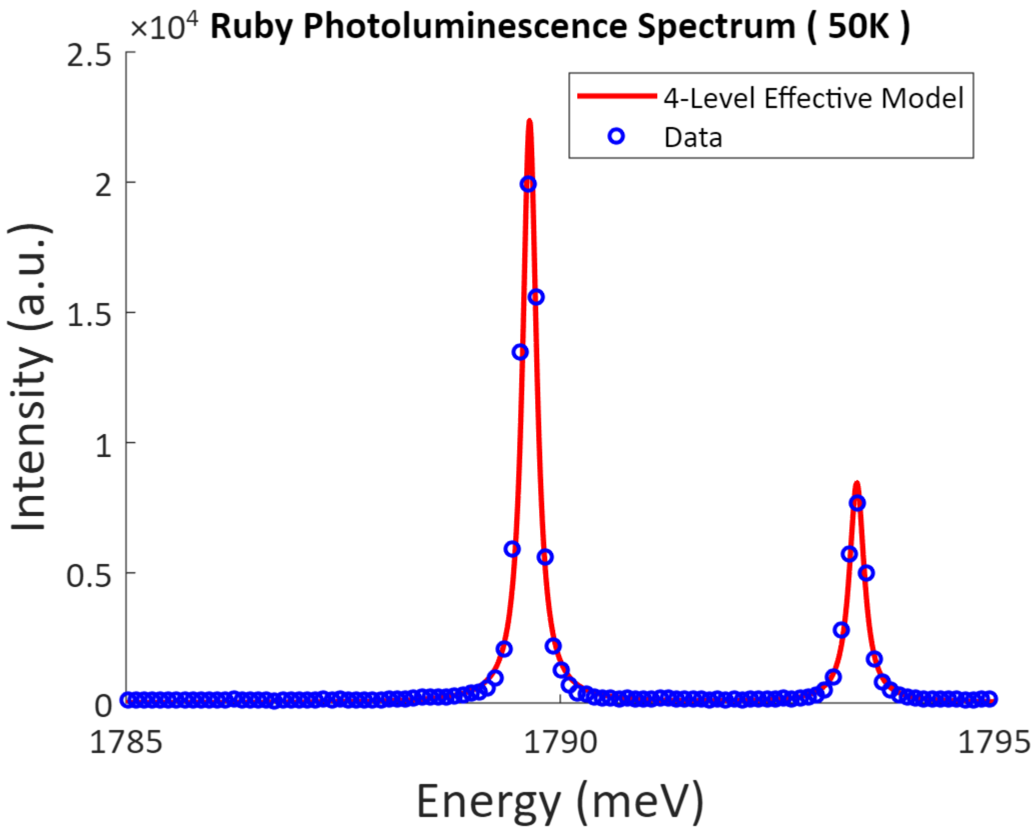

```
Fit Parameters :
T = 20 K
I0 = 2960
d_{20}/d_{10} = 1.274
Linewidths = [0.1849, 0.2209]
Delta = 3.765
E1 = 1790
```



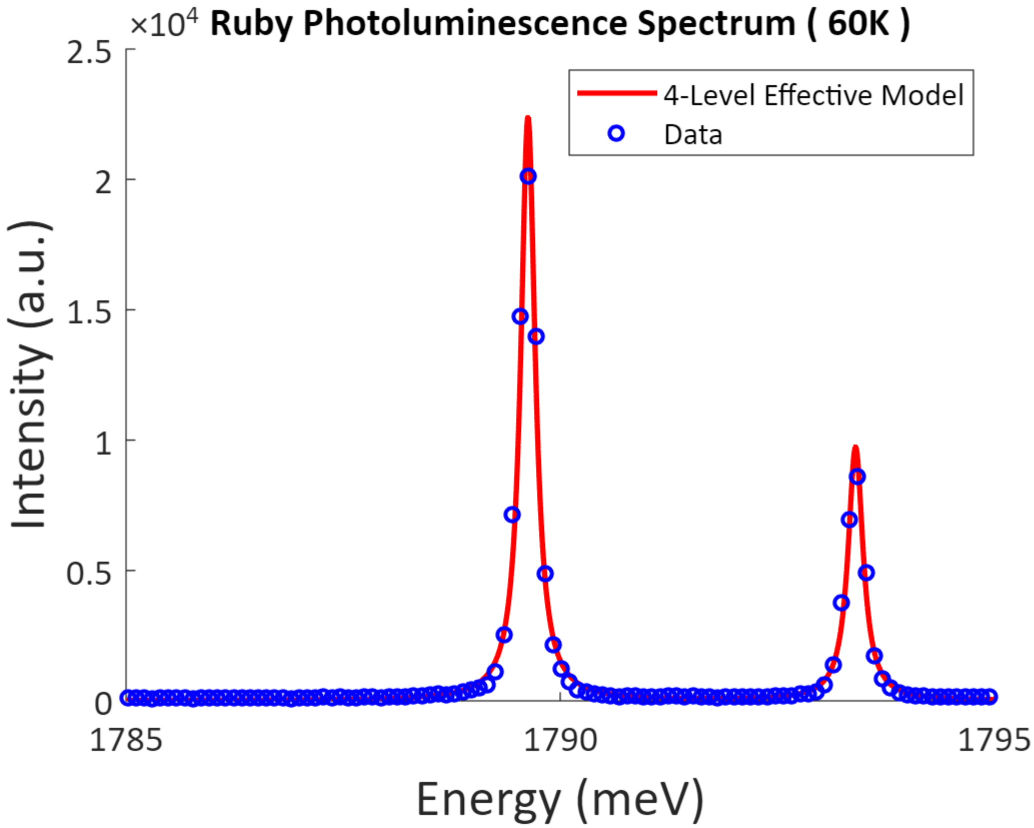

```
Fit Parameters :
T = 30 K
I0 = 2589
d_{20}/d_{10} = 1.065
Linewidths = [0.1902, 0.2111]
Delta = 3.767
E1 = 1790
```



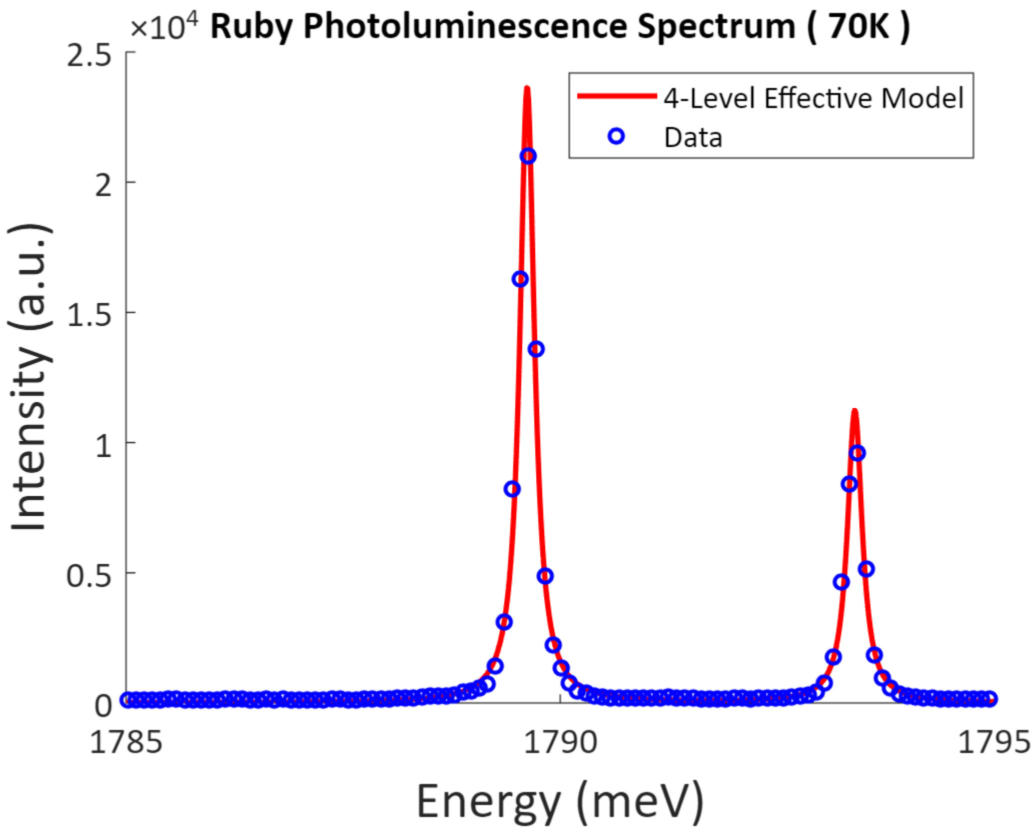

```
Fit Parameters :
T = 40 K
I0 = 2533
d_{20}/d_{10} = 1.008
Linewidths = [0.1942, 0.2076]
Delta = 3.768
E1 = 1790
```



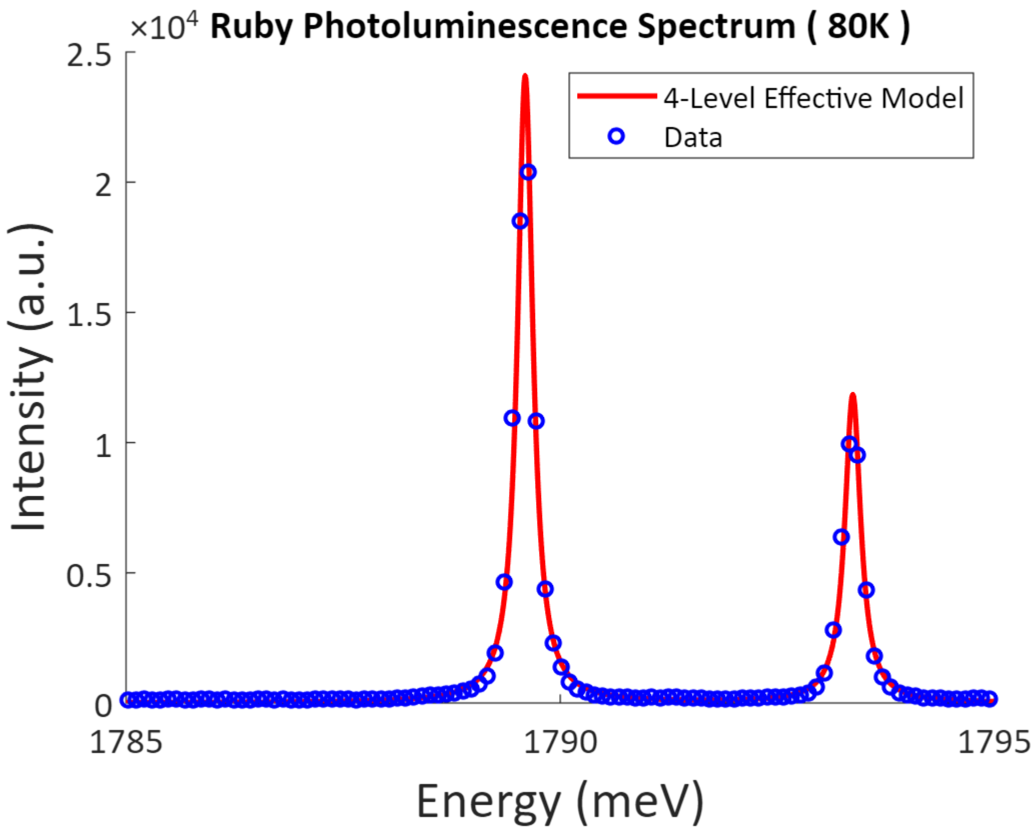

```
Fit Parameters :
T = 50 K
I0 = 2208
d_{20}/d_{10} = 0.9836
Linewidths = [0.1974, 0.2109]
Delta = 3.768
E1 = 1790
```



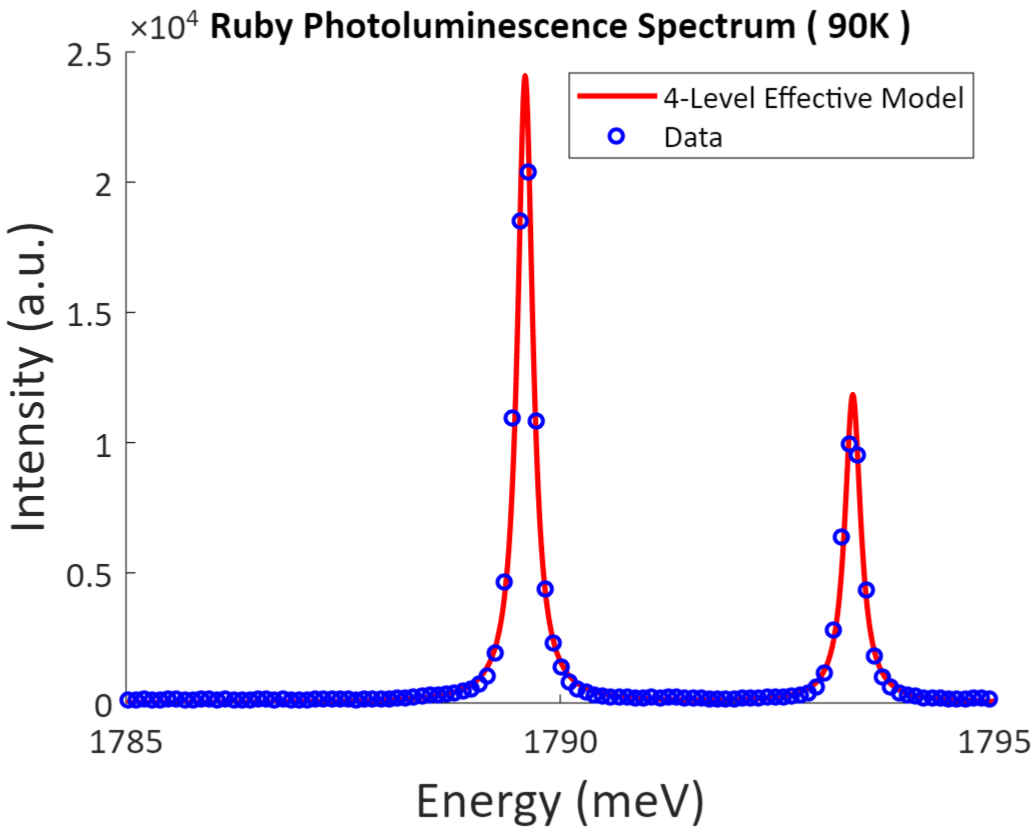

```
Fit Parameters :
T = 60 K
I0 = 2259
d_{20}/d_{10} = 0.968
Linewidths = [0.2016, 0.2098]
Delta = 3.772
E1 = 1790
```



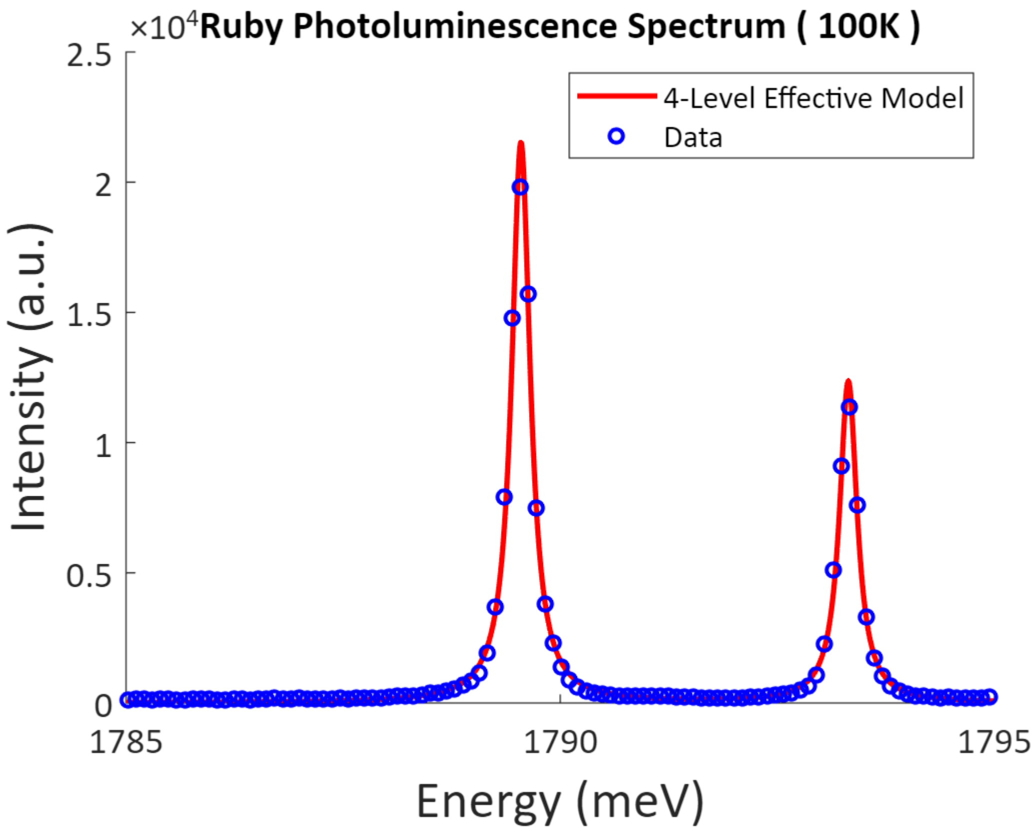

```
Fit Parameters :
T = 70 K
I0 = 2431
d_{20}/d_{10} = 0.9485
Linewidths = [0.2054, 0.2082]
Delta = 3.773
E1 = 1790
```



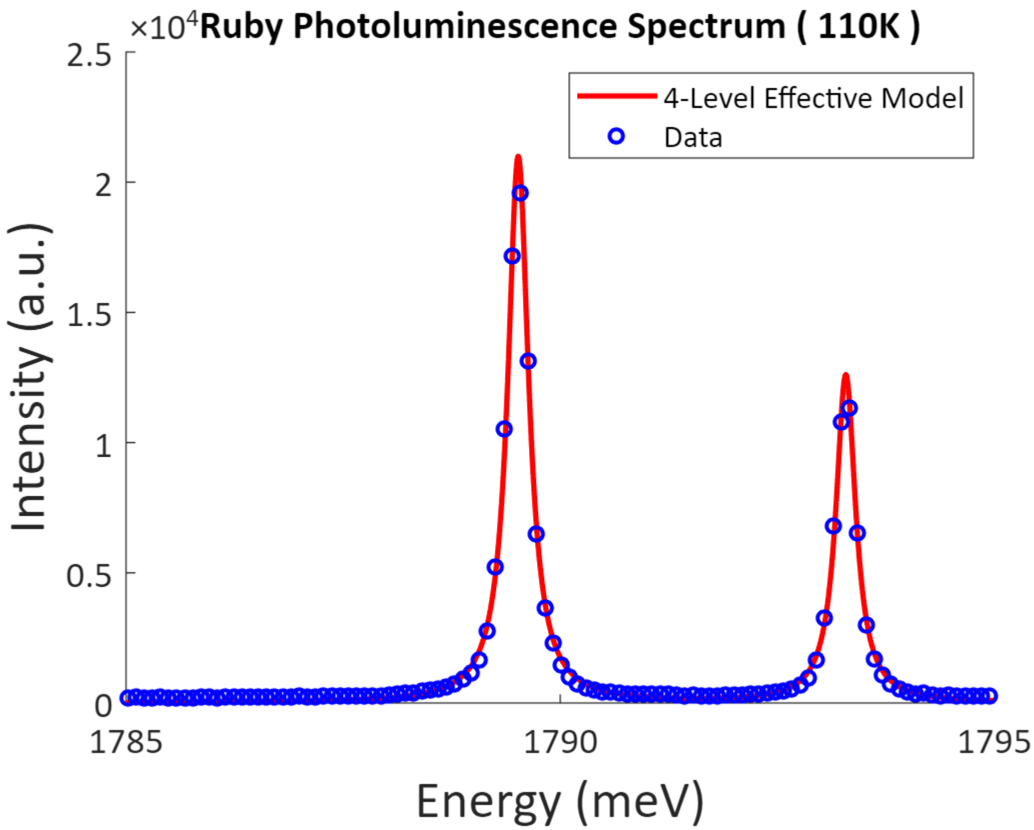

```
Fit Parameters :
T = 80 K
I0 = 2588
d_{20}/d_{10} = 0.9376
Linewidths = [0.2149, 0.2226]
Delta = 3.772
E1 = 1790
```



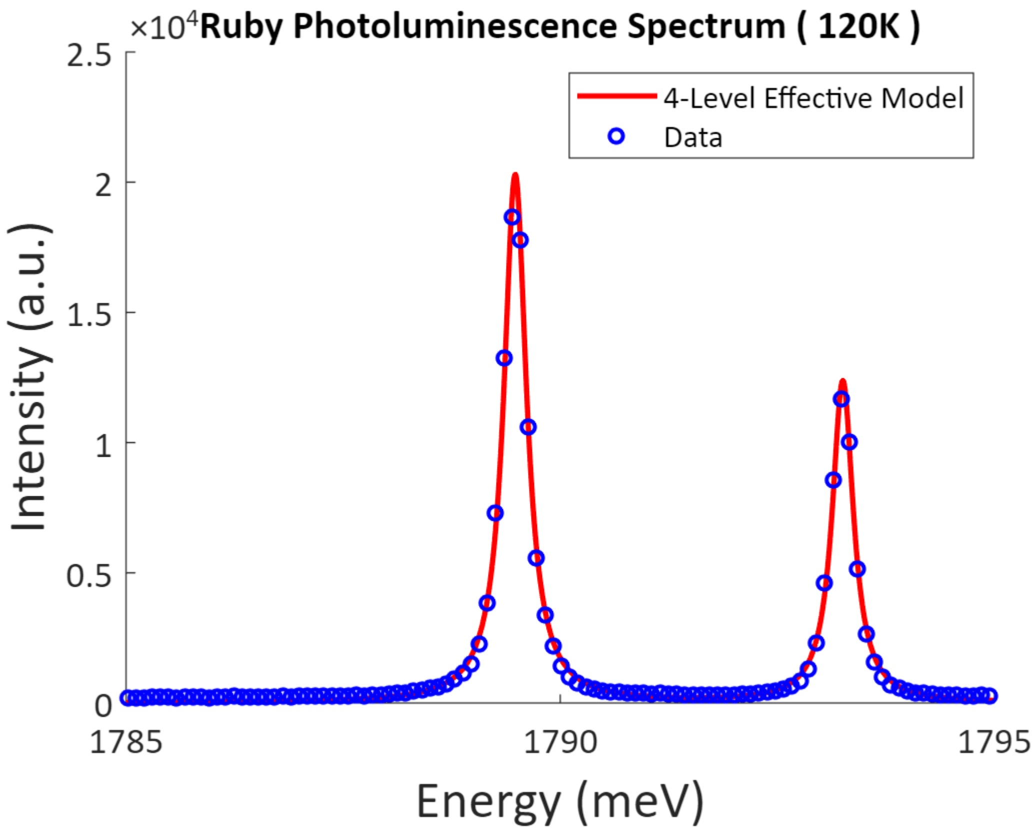

```
Fit Parameters :
T = 90 K
I0 = 2588
d_{20}/d_{10} = 0.9095
Linewidths = [0.2149, 0.2226]
Delta = 3.772
E1 = 1790
```



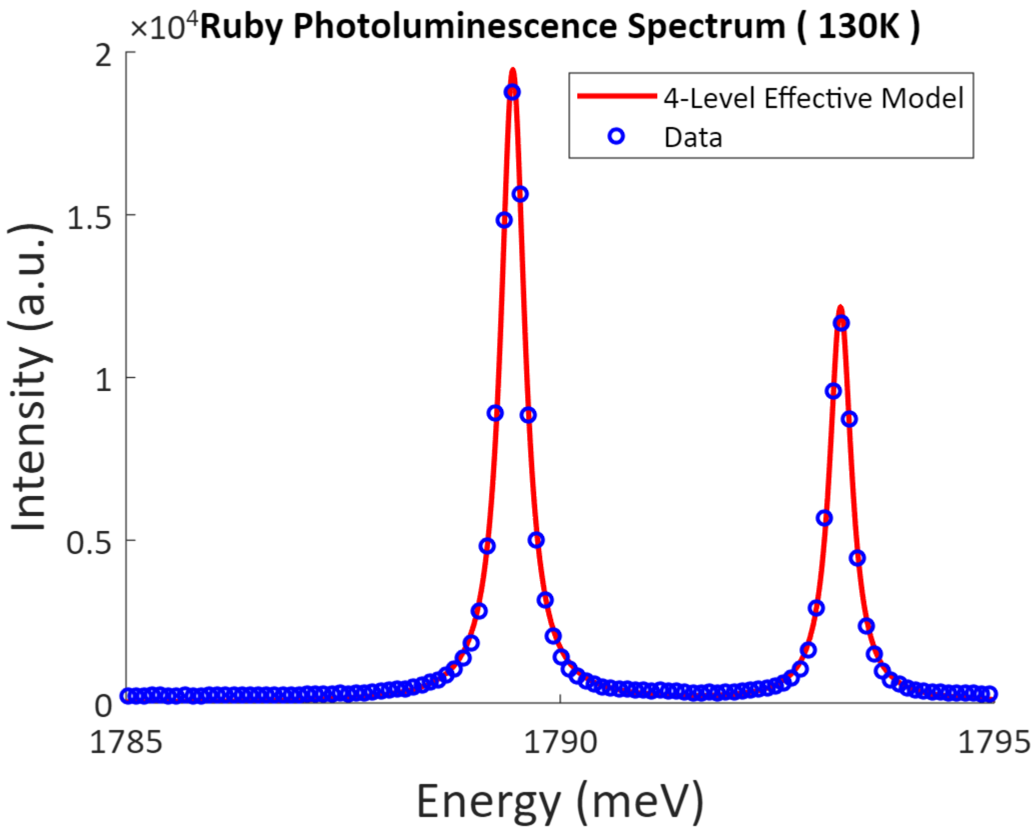

```
Fit Parameters :
T = 100 K
I0 = 2781
d_{20}/d_{10} = 0.9217
Linewidths = [0.2583, 0.2471]
Delta = 3.77
E1 = 1790
```



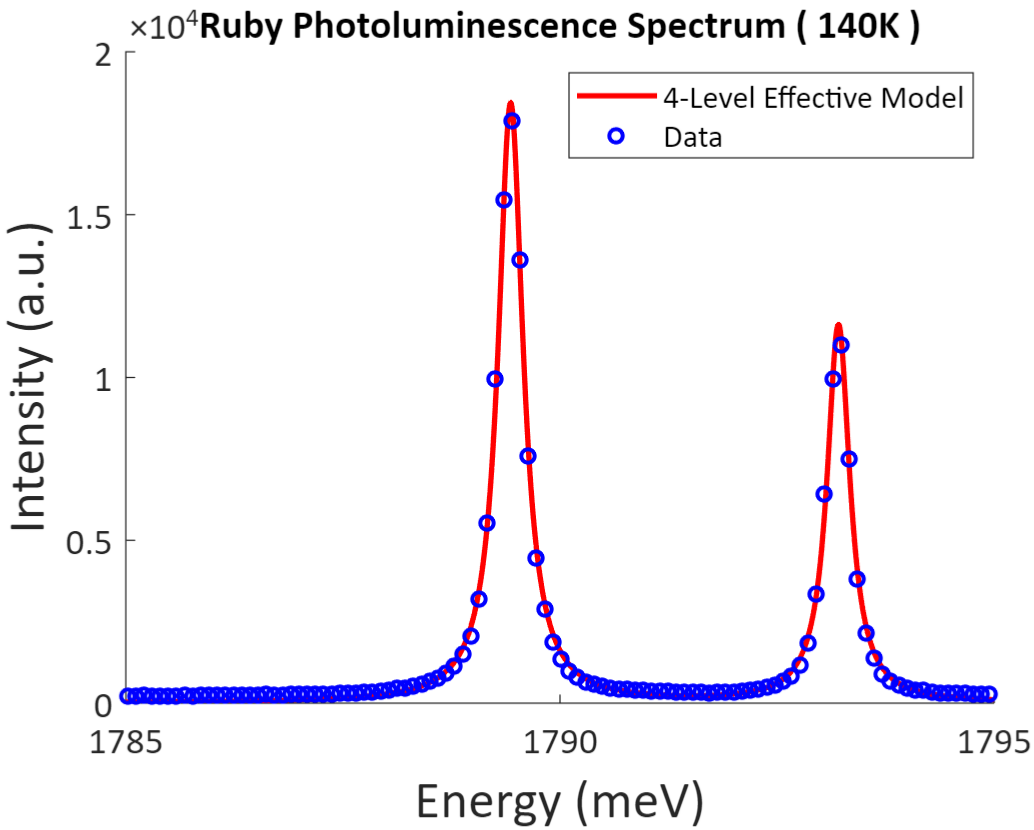

```
Fit Parameters :
T = 110 K
I0 = 3048
d_{20}/d_{10} = 0.9199
Linewidths = [0.2904, 0.2752]
Delta = 3.772
E1 = 1790
```



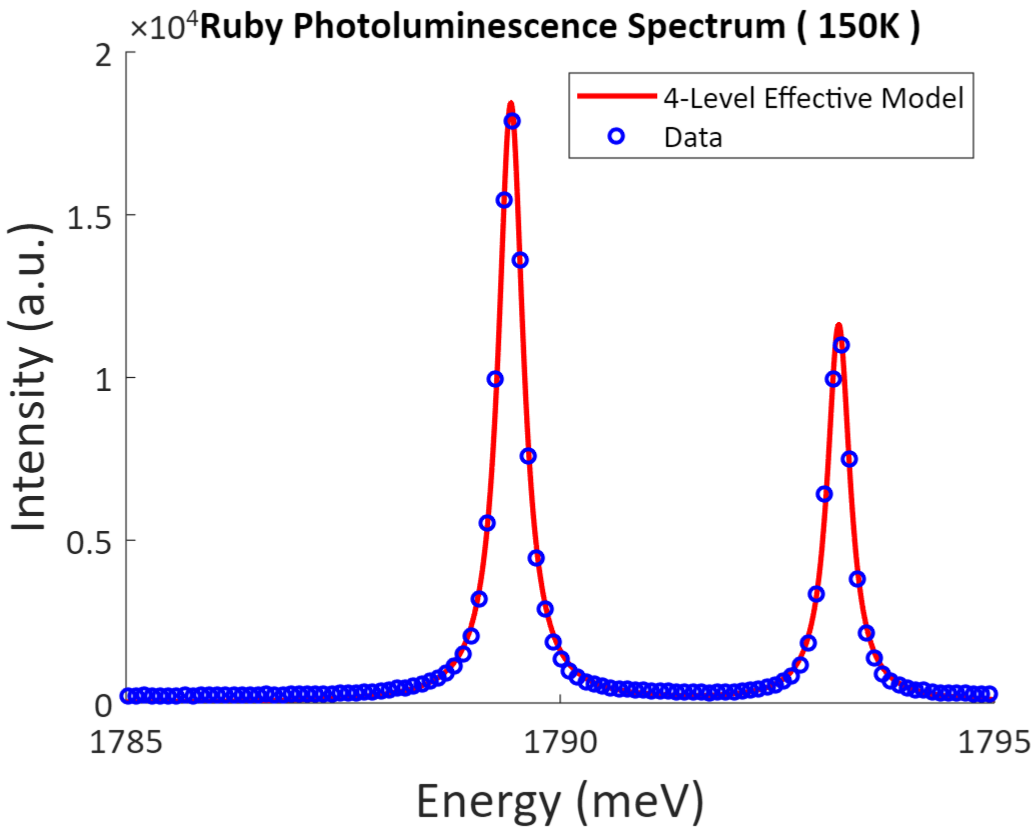

```
Fit Parameters :
T = 120 K
I0 = 3196
d_{20}/d_{10} = 0.9083
Linewidths = [0.315, 0.2962]
Delta = 3.772
E1 = 1789
```



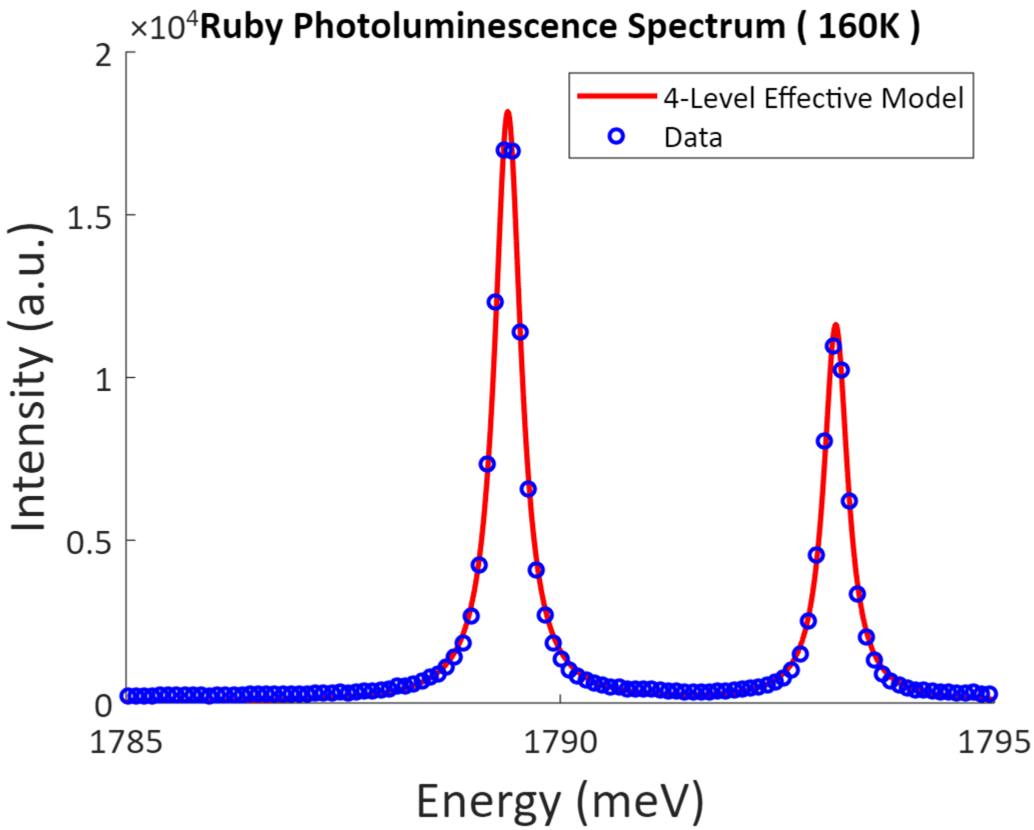

```
Fit Parameters :
T = 130 K
I0 = 3265
d_{20}/d_{10} = 0.8972
Linewidths = [0.3359, 0.3093]
Delta = 3.774
E1 = 1789
```



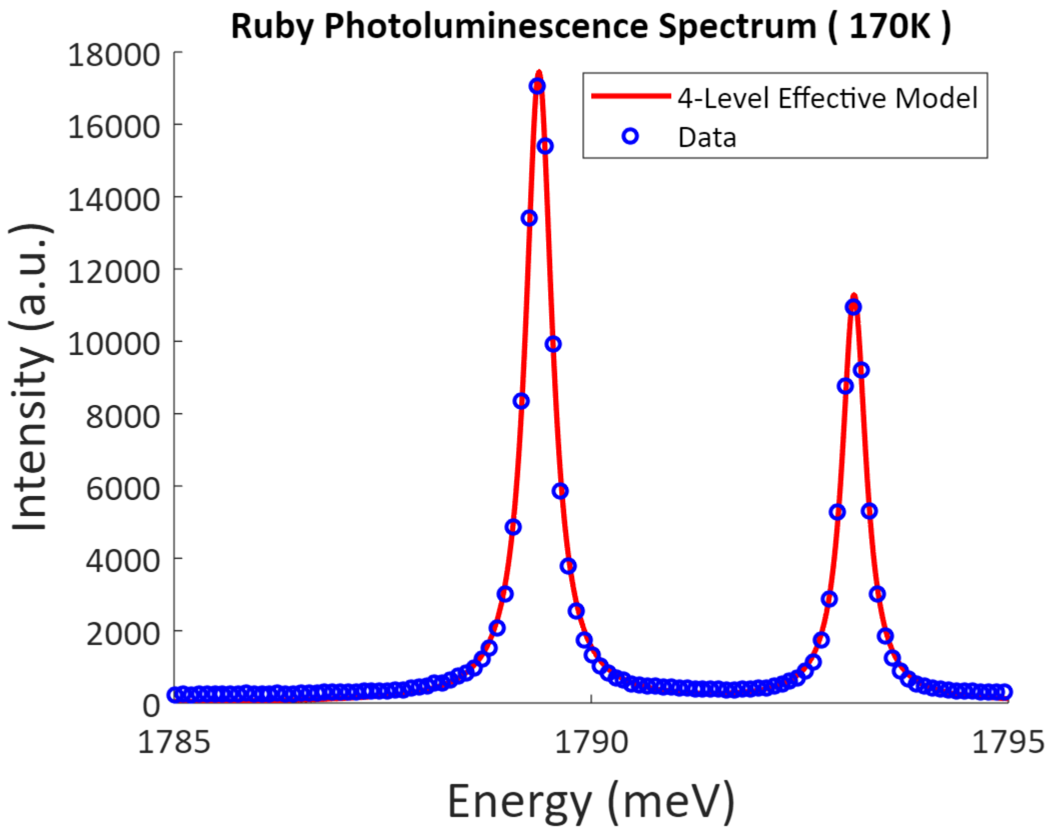

```
Fit Parameters :
T = 140 K
I0 = 3215
d_{20}/d_{10} = 0.8872
Linewidths = [0.349, 0.3191]
Delta = 3.775
E1 = 1789
```



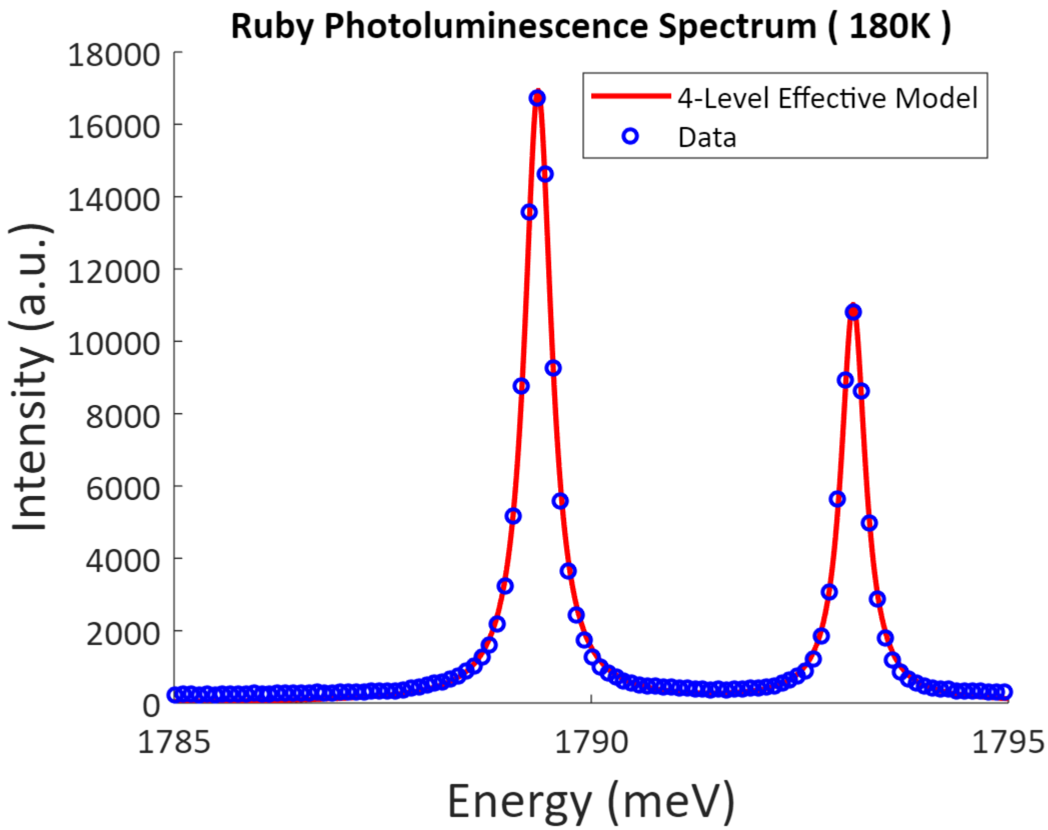

```
Fit Parameters :
T = 150 K
I0 = 3215
d_{20}/d_{10} = 0.878
Linewidths = [0.349, 0.3191]
Delta = 3.775
E1 = 1789
```



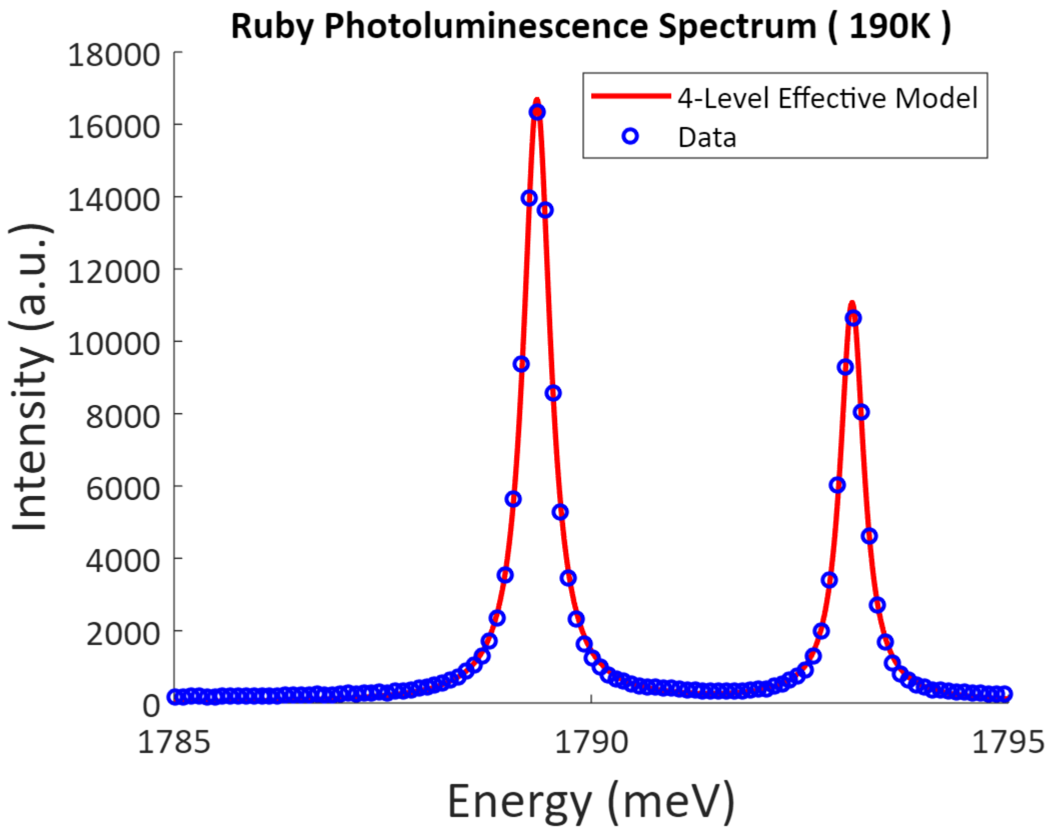

```
Fit Parameters :
T = 160 K
I0 = 3380
d_{20}/d_{10} = 0.8728
Linewidths = [0.3725, 0.3379]
Delta = 3.777
E1 = 1789
```



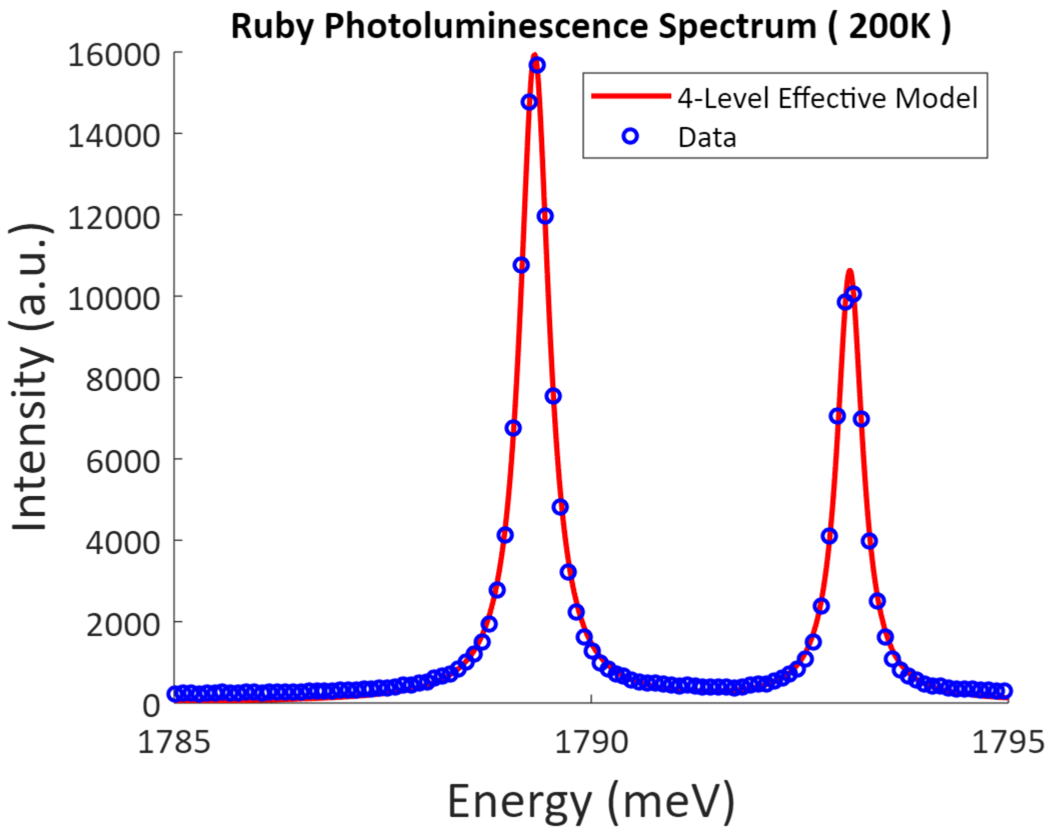

```
Fit Parameters :
T = 170 K
I0 = 3385
d_{20}/d_{10} = 0.8657
Linewidths = [0.3885, 0.3488]
Delta = 3.777
E1 = 1789
```



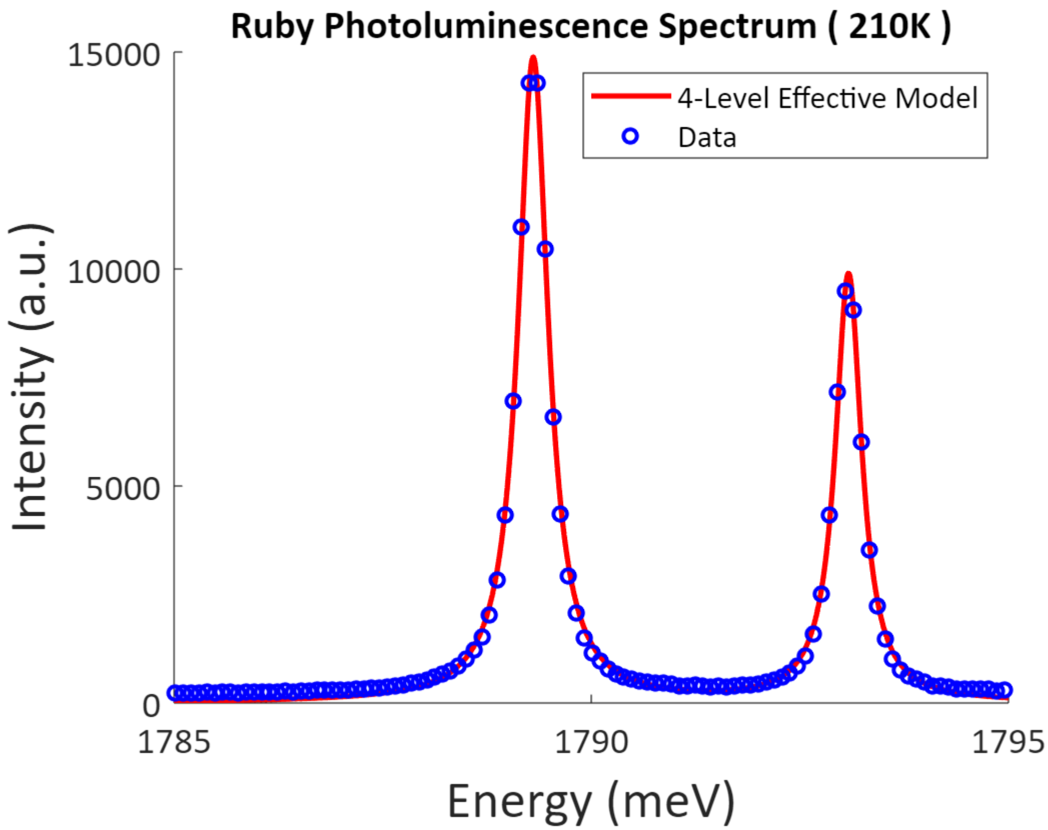

```
Fit Parameters :
T = 180 K
I0 = 3364
d_{20}/d_{10} = 0.8608
Linewidths = [0.3977, 0.3558]
Delta = 3.776
E1 = 1789
```



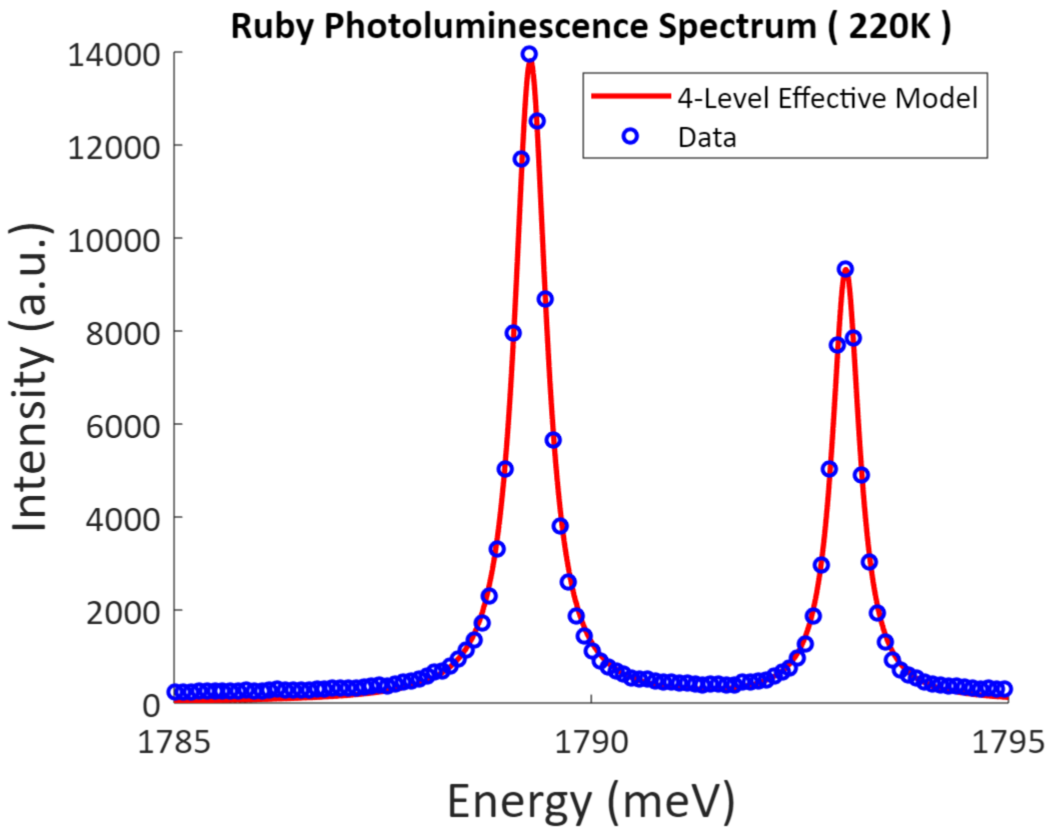

```
Fit Parameters :
T = 190 K
I0 = 3308
d_{20}/d_{10} = 0.8546
Linewidths = [0.3968, 0.3478]
Delta = 3.777
E1 = 1789
```



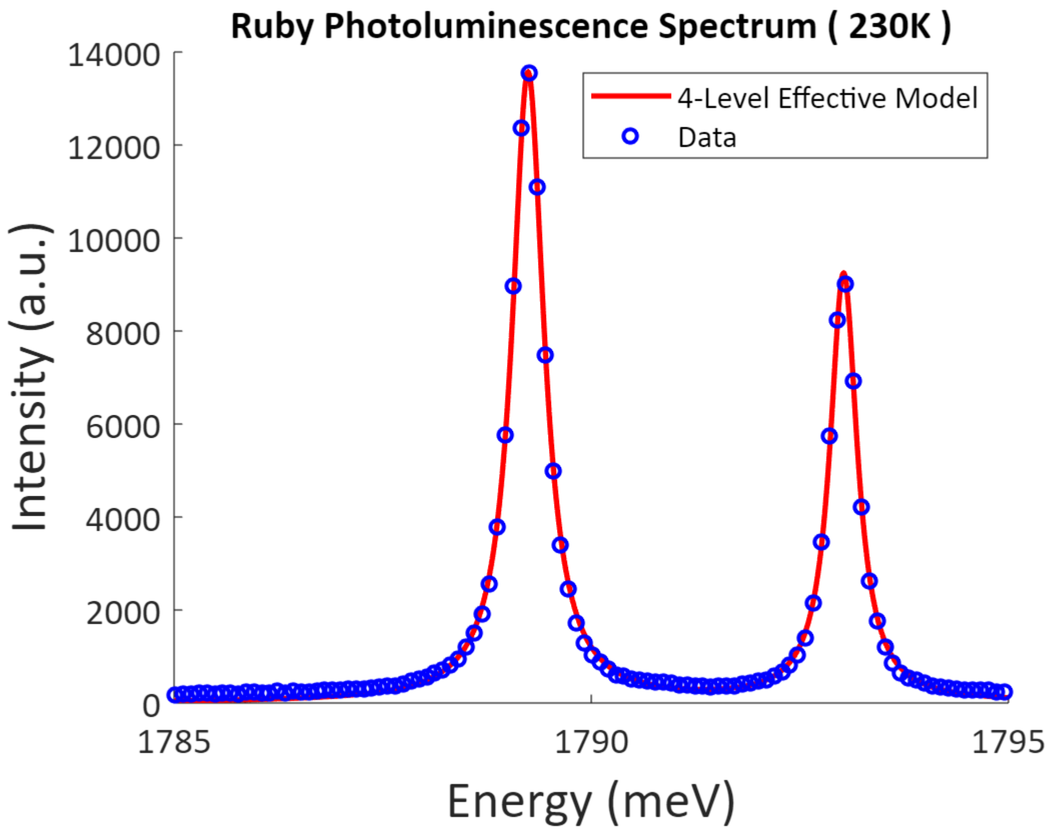

```
Fit Parameters :
T = 200 K
I0 = 3400
d_{20}/d_{10} = 0.8534
Linewidths = [0.4274, 0.3756]
Delta = 3.778
E1 = 1789
```



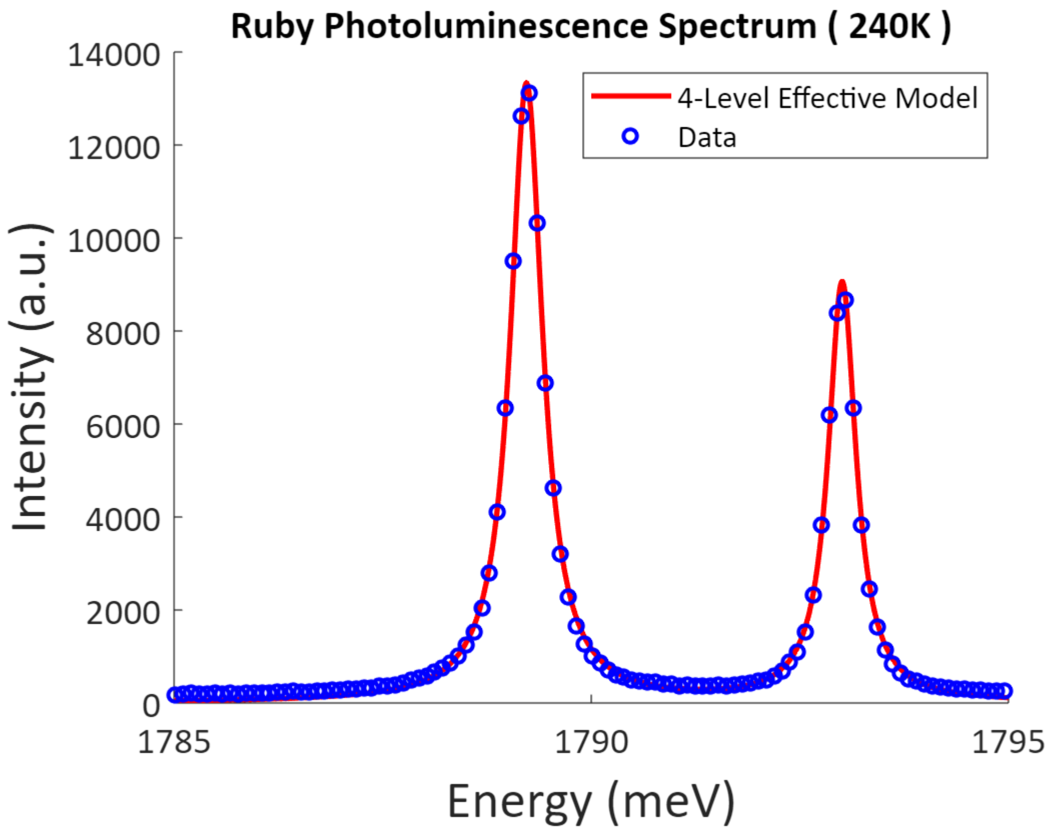

```
Fit Parameters :
T = 210 K
I0 = 3253
d_{20}/d_{10} = 0.8468
Linewidths = [0.4379, 0.3841]
Delta = 3.779
E1 = 1789
```



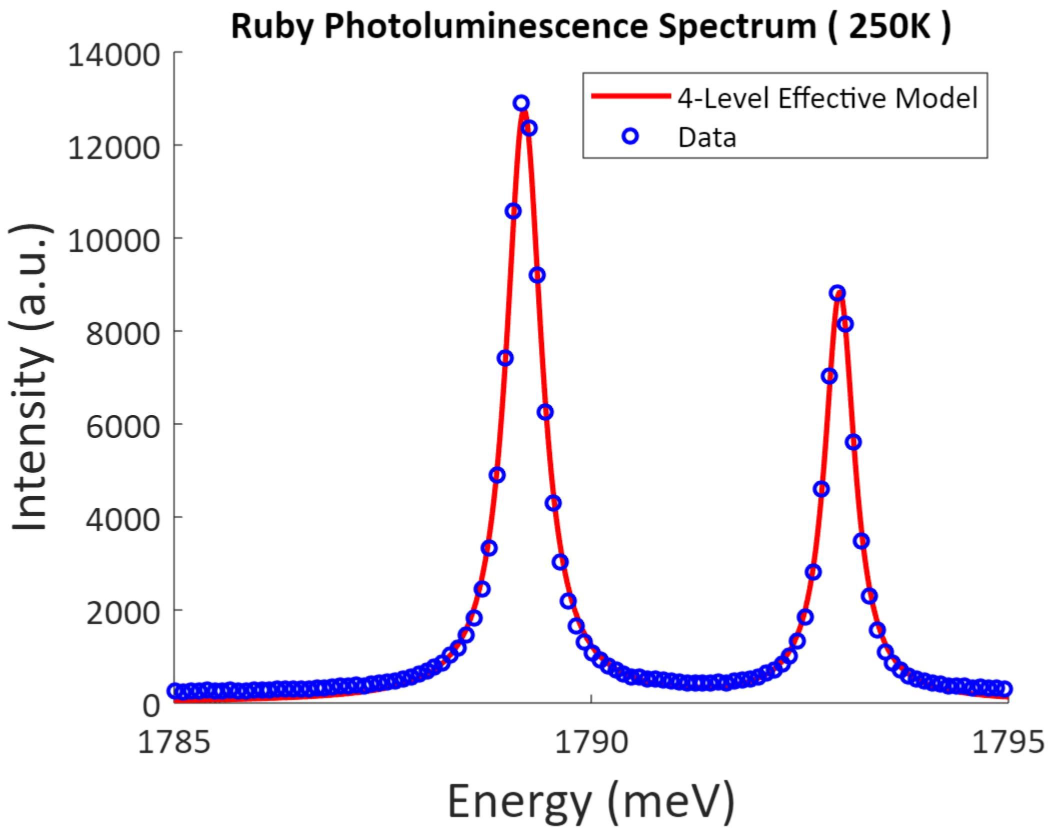

```
Fit Parameters :
T = 220 K
I0 = 3214
d_{20}/d_{10} = 0.8429
Linewidths = [0.4661, 0.4033]
Delta = 3.781
E1 = 1789
```



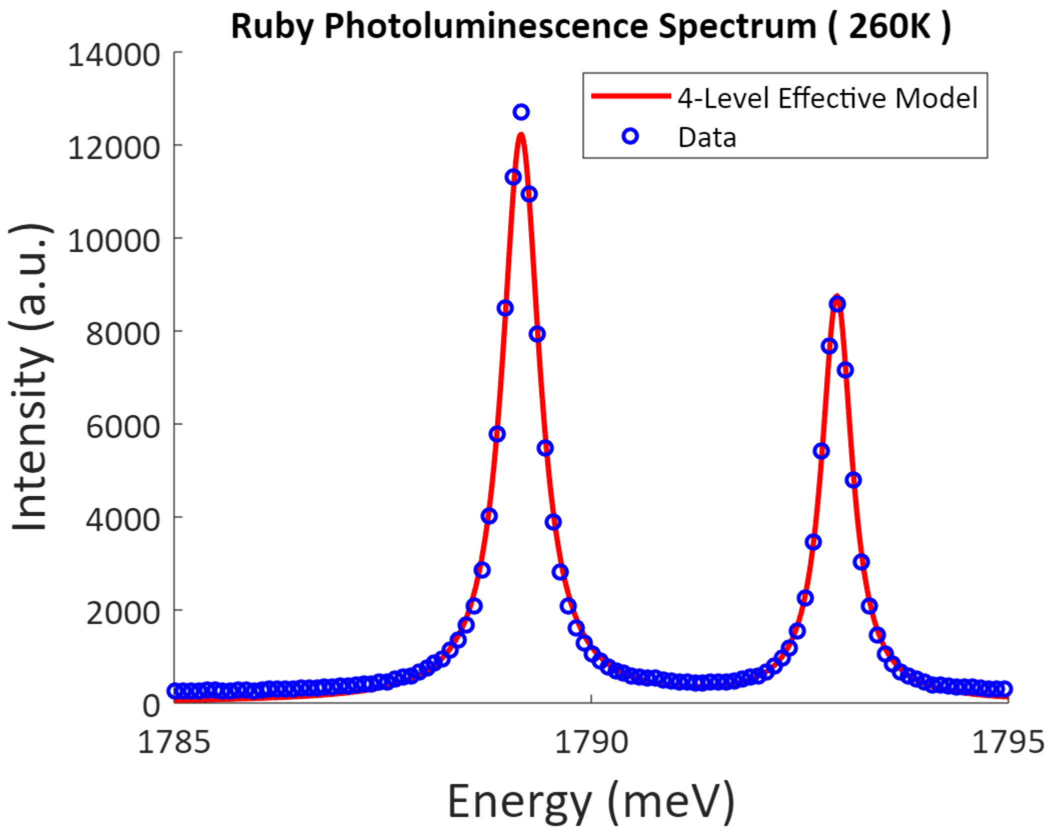

```
Fit Parameters :
T = 230 K
I0 = 3151
d_{20}/d_{10} = 0.8388
Linewidths = [0.4652, 0.3981]
Delta = 3.782
E1 = 1789
```



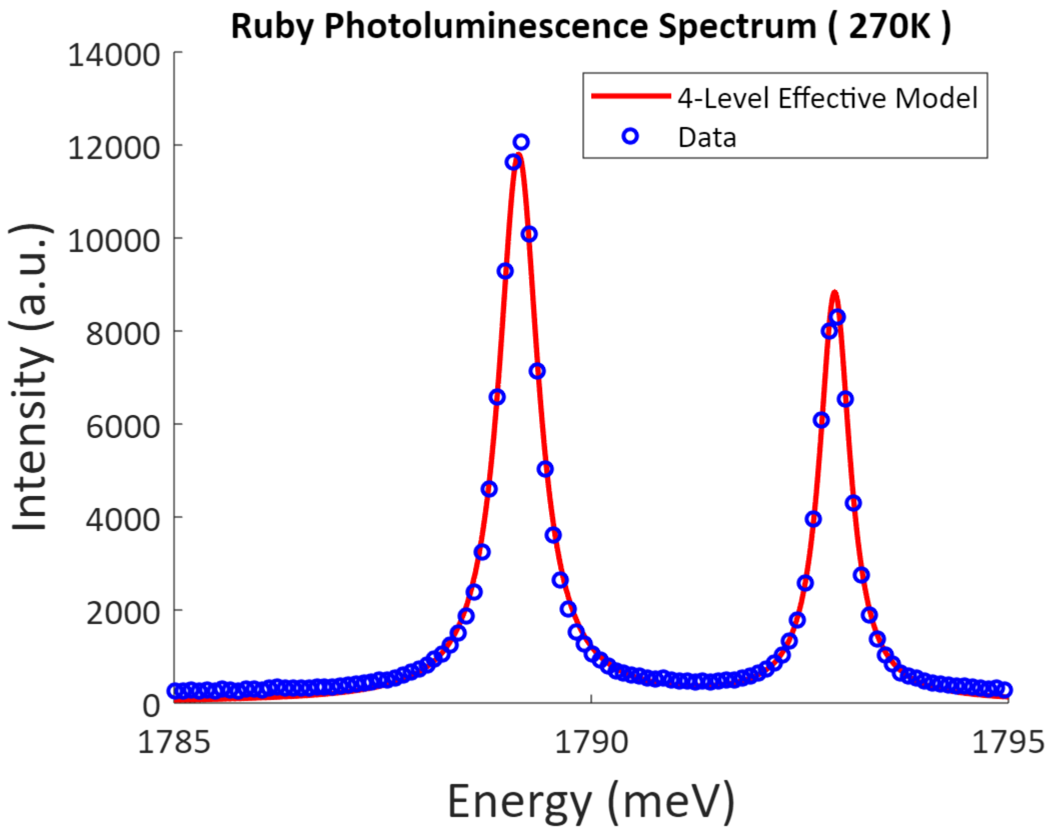

```
Fit Parameters :
T = 240 K
I0 = 3140
d_{20}/d_{10} = 0.8356
Linewidths = [0.4718, 0.4049]
Delta = 3.783
E1 = 1789
```



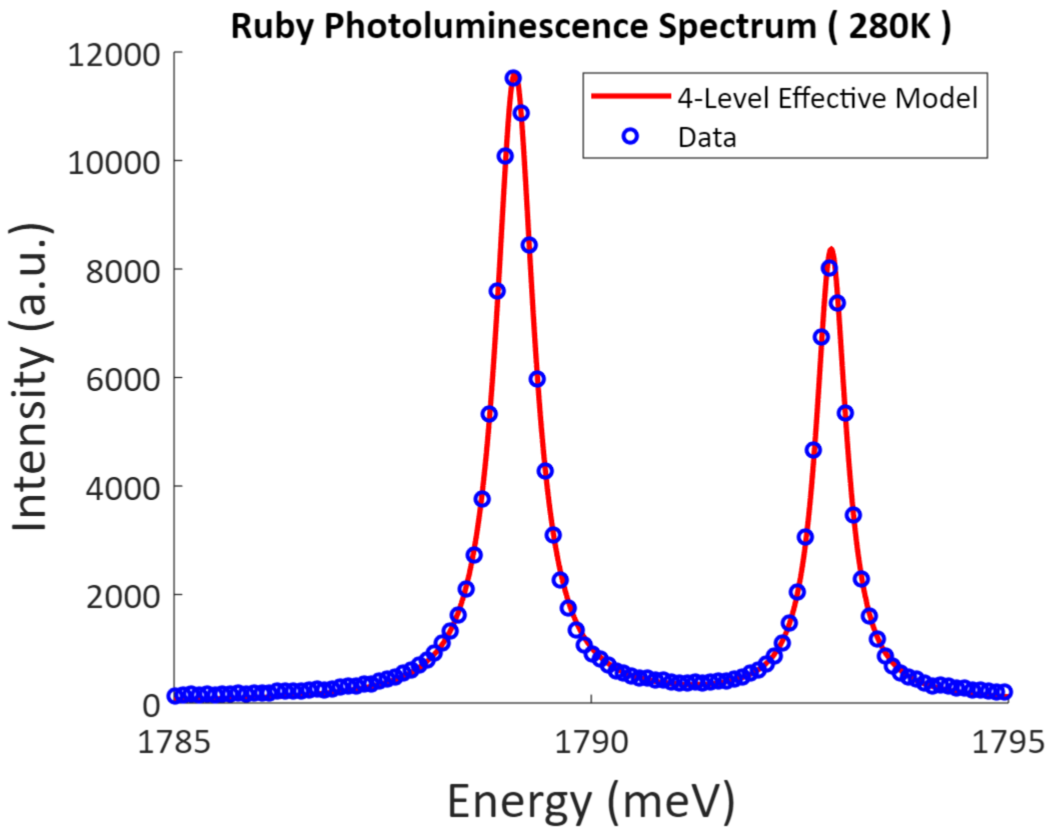

```
Fit Parameters :
T = 250 K
I0 = 3302
d_{20}/d_{10} = 0.8354
Linewidths = [0.519, 0.4403]
Delta = 3.785
E1 = 1789
```



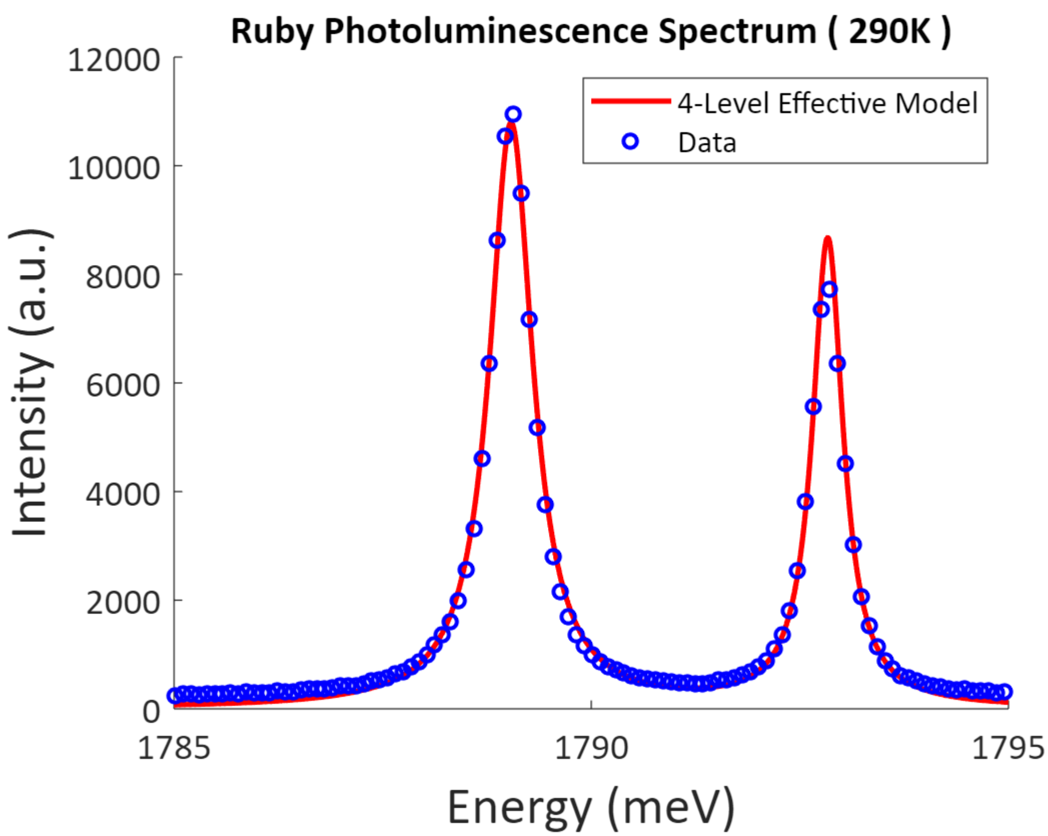

```
Fit Parameters :
T = 260 K
I0 = 3339
d_{20}/d_{10} = 0.83
Linewidths = [0.5472, 0.4467]
Delta = 3.786
E1 = 1789
```




```
Fit Parameters :
T = 270 K
I0 = 3398
d_{20}/d_{10} = 0.8238
Linewidths = [0.5773, 0.4467]
Delta = 3.789
E1 = 1789
```




```
Fit Parameters :
T = 280 K
I0 = 3213
d_{20}/d_{10} = 0.8221
Linewidths = [0.554, 0.4467]
Delta = 3.79
E1 = 1789
```




```
Fit Parameters :
T = 290 K
I0 = 3396
d_{20}/d_{10} = 0.8116
Linewidths = [0.631, 0.4467]
Delta = 3.795
E1 = 1789
```

Fit Room Temperature Ruby Data at 7 Different Temperatures, to 4-level Effective Model

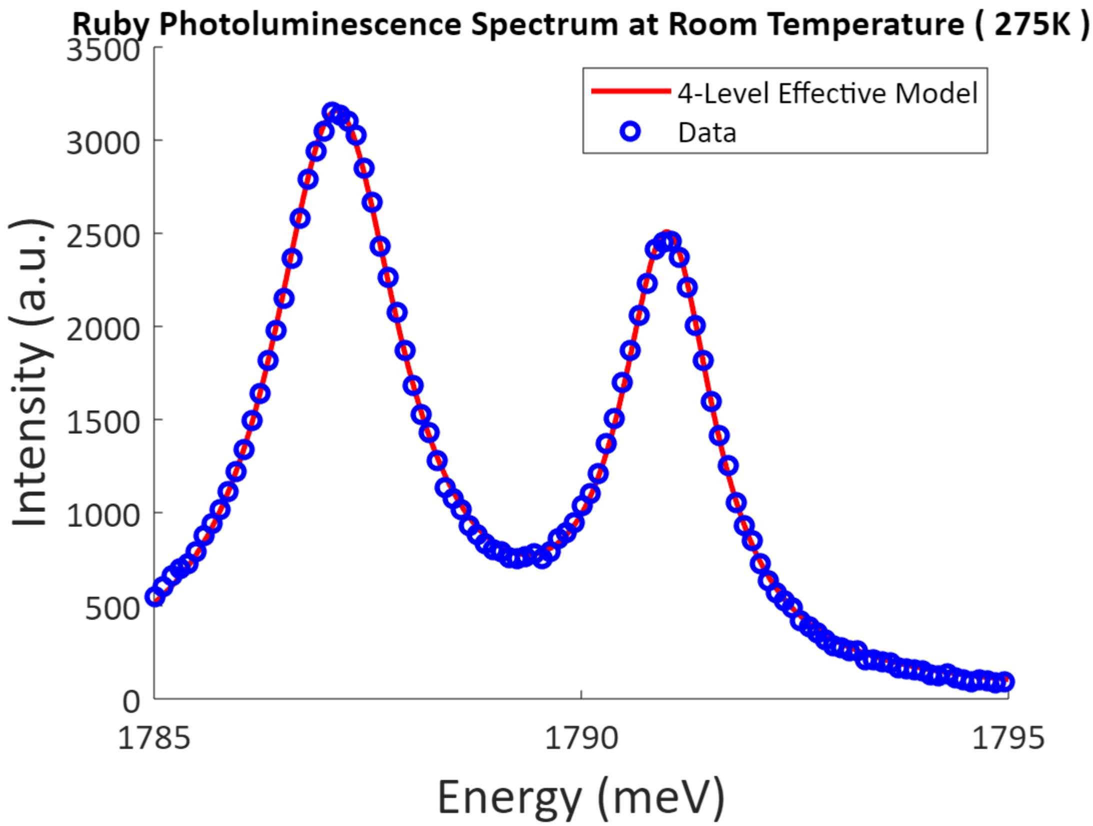
```
% photon energy range
Erange = [1785, 1795];
Energy = linspace(Erange(1), Erange(2), 1000);

% lower and upper bounds of fitting parameters
LowerBound = [500, 0.5, 0, 0, 3.5, 1785];
UpperBound = [3000, 3, 1, 1, 4, 1795];

% variables to store fit parameters
I0 = zeros(7,1);
TransAmpR = zeros(7,1);
Linewidth = zeros(7,2);
Delta = zeros(7,1);
E1 = zeros(7,1);

% try fitting for 7 different temperatures
```

```matlab
for itN = 1:7

    T = 5*(itN+54);    % temperature

    % choose data near the peaks
    Idx = RubyRoomData(:,1) > Erange(1) & RubyRoomData(:,1) < Erange(2);
    E_data = RubyRoomData(Idx,1);
    I_data = RubyRoomData(Idx,2);

    % make parameter bounds and loss function into a single struct variable
    options.lb = LowerBound;
    options.ub = UpperBound;
    options.loss_type = loss_func;

    % define fitting curve
    FitModel = @(Params, Energies) Spec_4lev(Params(1), Params(2), [power(10,
Params(3)), power(10, Params(4))], Params(5), Params(6), T, Energies);

    % iterate to find best fit
    best_loss = Inf;
    for it = 1:3
        options.rng_seed = it;          % Try different seeds
        Params0 = rand(1,6) .* (UpperBound - LowerBound) + LowerBound;      % try
different initial parameters
        [params_i, loss_hist_i] = de_curve_fit(FitModel, E_data, I_data, Params0,
options);     % differential evolution fitting
        if loss_hist_i(end) < best_loss
            best_loss = loss_hist_i(end);
            FitParams = params_i;
            loss_history = loss_hist_i;
        end
    end

    I0(itN) = FitParams(1);
    TransAmpR(itN) = FitParams(2);
    Linewidth(itN,:) = [power(10, FitParams(3)), power(10, FitParams(4))];
    Delta(itN) = FitParams(5);
    E1(itN) = FitParams(6);

    % show message
    disptime(['T = ', sprintf('%d', T), 'K | loss = ', sprintf('%.4g', best_loss)]);
end
```

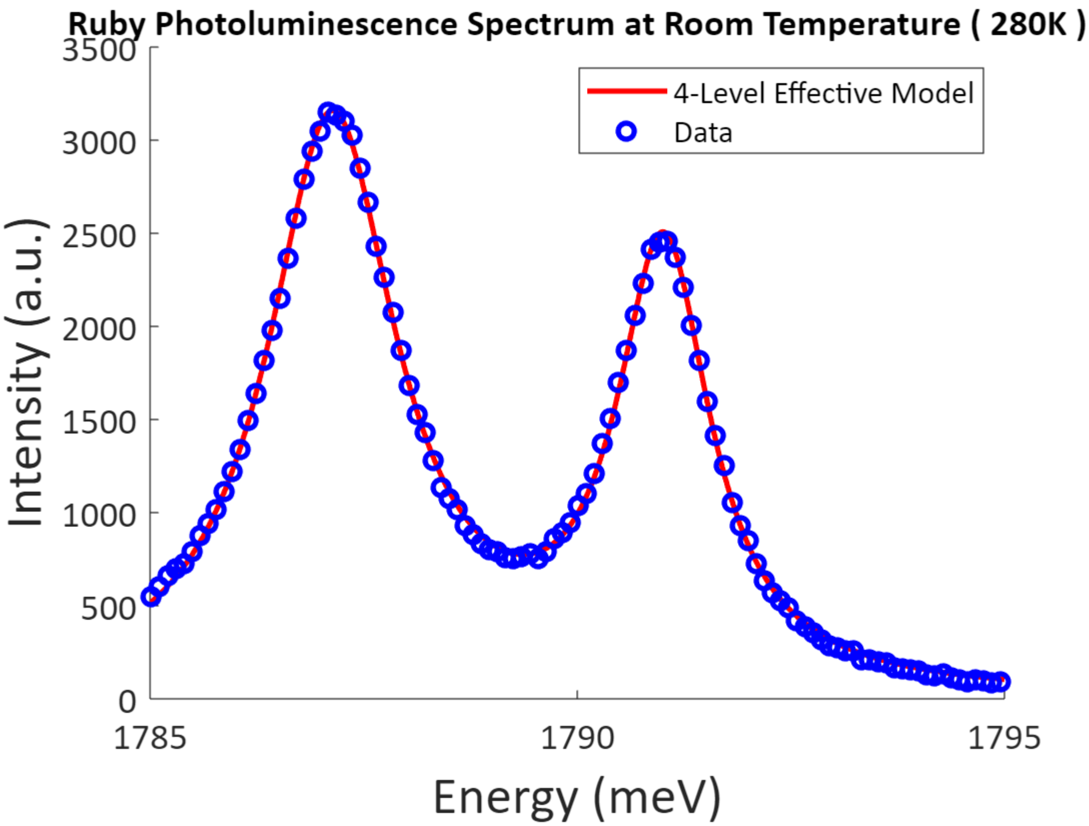
```
25-06-10 08:54:16 | T = 275K | loss = 0.5606
25-06-10 08:54:19 | T = 280K | loss = 0.5606
25-06-10 08:54:23 | T = 285K | loss = 0.5606
25-06-10 08:54:26 | T = 290K | loss = 0.5606
25-06-10 08:54:30 | T = 295K | loss = 0.5606
25-06-10 08:54:33 | T = 300K | loss = 0.5606
25-06-10 08:54:37 | T = 305K | loss = 0.5606
```

Plot Room Temperature Ruby Data with Fit Curve

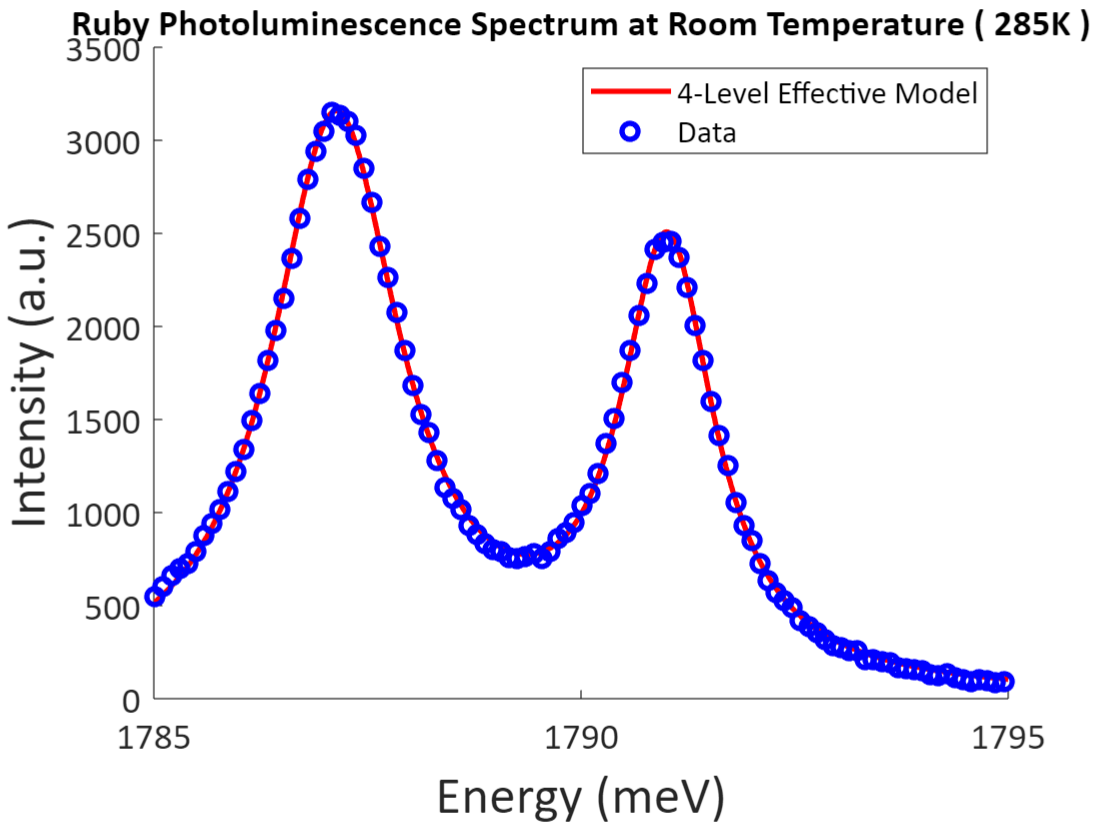
```
for itN = 1:7

    T = 5*(itN+54);    % temperature

    % choose data near the peaks
    Idx = RubyRoomData(:,1) > Erange(1) & RubyRoomData(:,1) < Erange(2);
    E_data = RubyRoomData(Idx,1);
    I_data = RubyRoomData(Idx,2);

    % plot
    figure;
    hold on;
    I_fit = Spec_4lev(I0(itN), TransAmpR(itN), Linewidth(itN,:), Delta(itN),
E1(itN), T, Energy);
    plot(Energy, I_fit, 'color', 'red', 'LineWidth', 2);
    plot(E_data, I_data, 'o', 'color', 'blue', 'LineWidth', 2);
    ax = gca;
    ax.FontSize = 14;
    ax.FontName = 'Calibri';
    xlabel('Energy (meV)', 'FontName', 'Calibri', 'FontSize', 20);
    ylabel('Intensity (a.u.)', 'FontName', 'Calibri', 'FontSize', 20);
    title(['Ruby Photoluminescence Spectrum at Room Temperature ( ', sprintf('%d',
T), 'K )'], 'FontName', 'Calibri', 'FontSize', 14);
    legend({'4-Level Effective Model', 'Data'}, 'Location','northeast', 'FontName',
'Calibri', 'FontSize', 12);
    hold off;

    % show fit parameters
    disp('Fit Parameters :')
    disp(['T = ', sprintf('%d', T), ' K']);
    disp(['I0 = ', sprintf('%.4g', I0(itN))]);
    disp(['d_{20}/d_{10} = ', sprintf('%.4g', TransAmpR(itN))]);
    disp(['Linewidths = [', sprintf('%.4g', Linewidth(itN,1)), ', ',
sprintf('%.4g', Linewidth(itN,2)) ']']);
    disp(['Delta = ', sprintf('%.4g', Delta(itN))]);
    disp(['E1 = ', sprintf('%.4g', E1(itN))]);
end
```



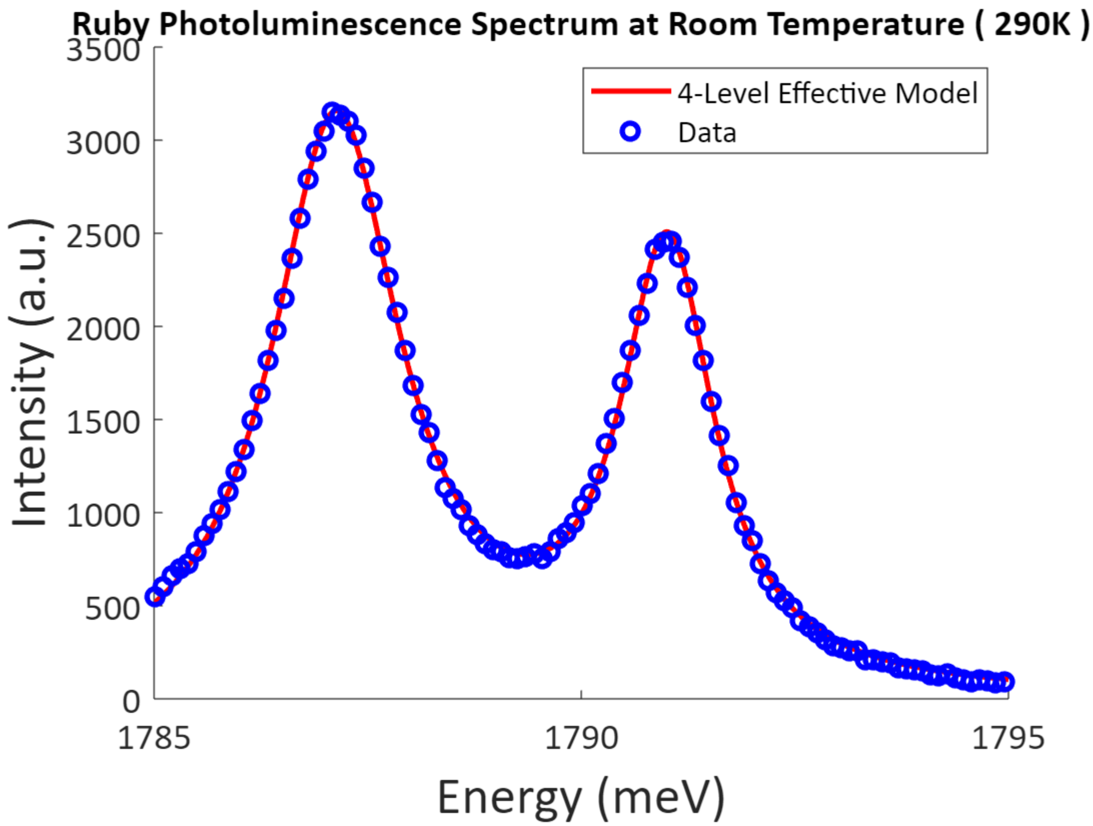

```
Fit Parameters :
T = 275 K
I0 = 2845
d_{20}/d_{10} = 0.8007
Linewidths = [1.84, 1.322]
Delta = 3.879
E1 = 1787
```



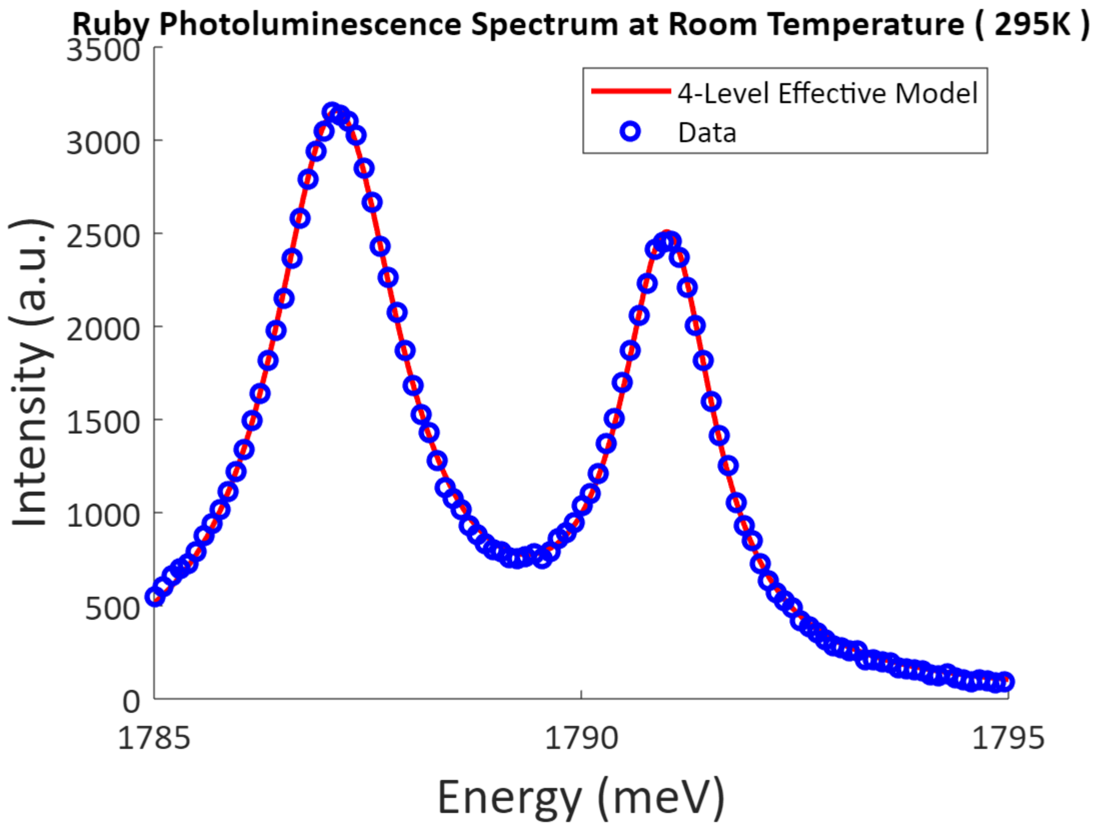

```
Fit Parameters :
T = 280 K
I0 = 2845
d_{20}/d_{10} = 0.7995
Linewidths = [1.84, 1.322]
Delta = 3.879
E1 = 1787
```



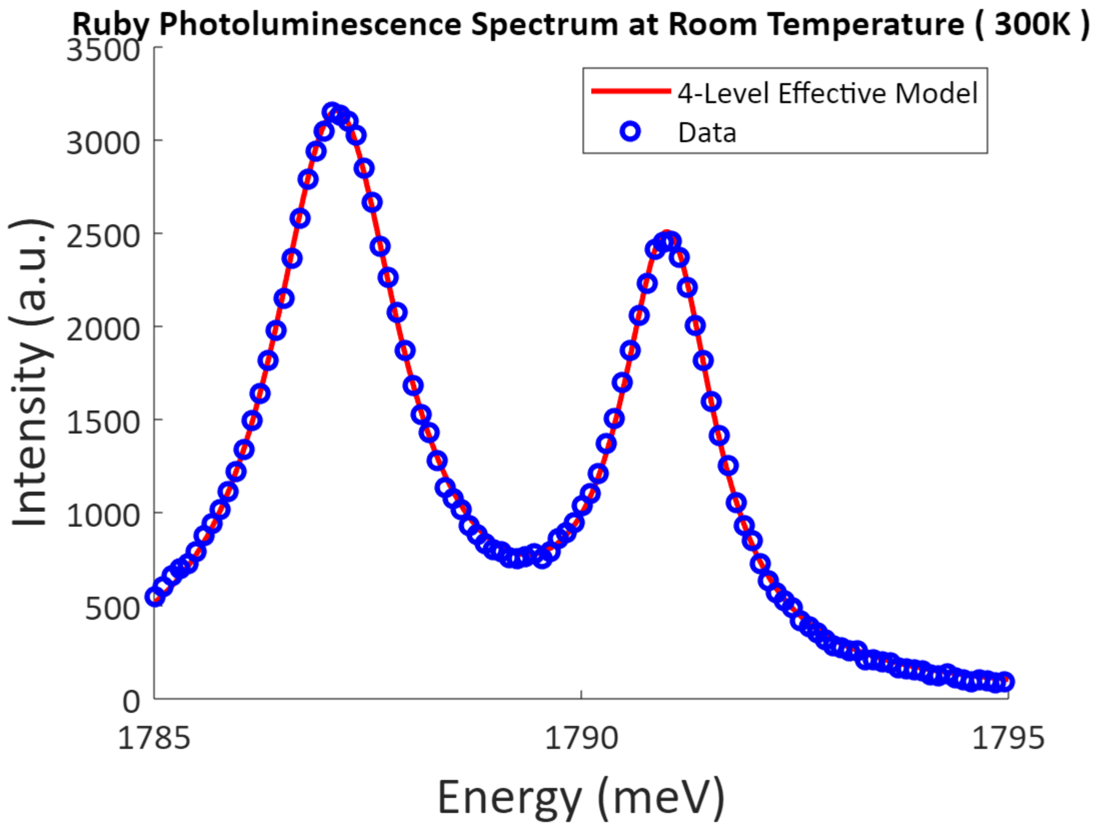

```
Fit Parameters :
T = 285 K
I0 = 2845
d_{20}/d_{10} = 0.7984
Linewidths = [1.84, 1.322]
Delta = 3.879
E1 = 1787
```



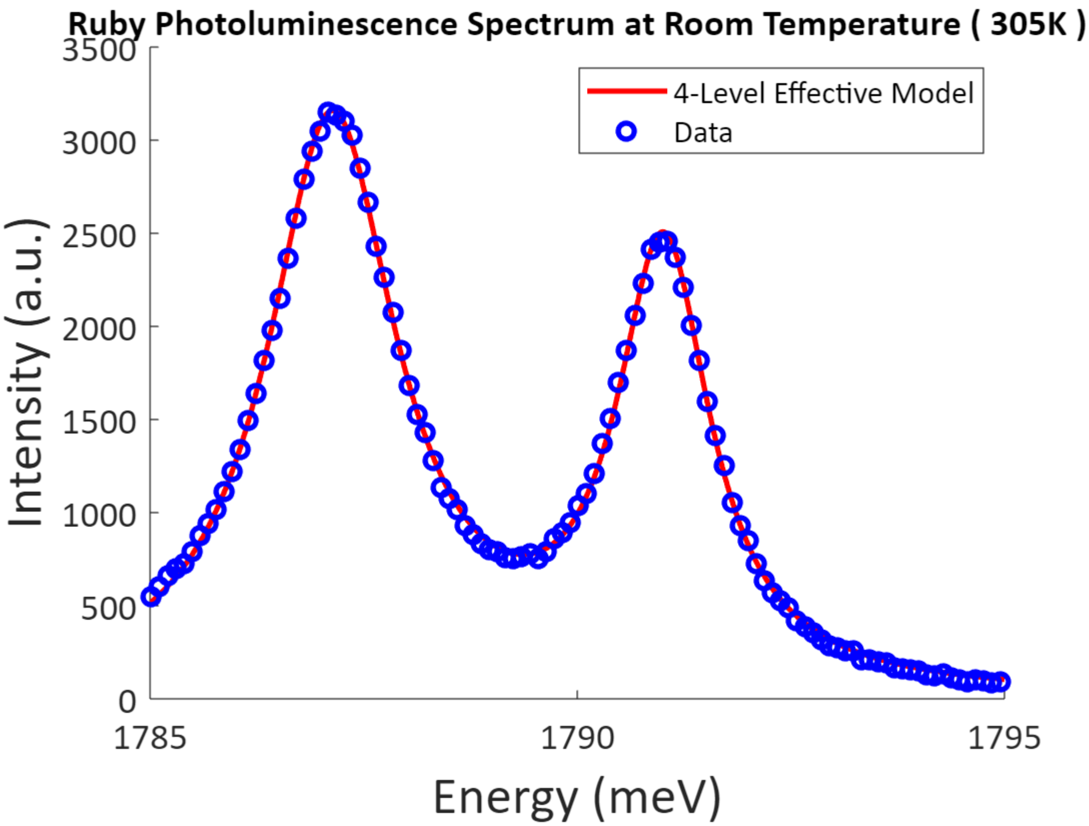

```
Fit Parameters :
T = 290 K
I0 = 2845
d_{20}/d_{10} = 0.7973
Linewidths = [1.84, 1.322]
Delta = 3.879
E1 = 1787
```




```
Fit Parameters :
T = 295 K
I0 = 2845
d_{20}/d_{10} = 0.7963
Linewidths = [1.84, 1.322]
Delta = 3.879
E1 = 1787
```




```
Fit Parameters :
T = 300 K
I0 = 2845
d_{20}/d_{10} = 0.7953
Linewidths = [1.84, 1.322]
Delta = 3.879
E1 = 1787
```




```
Fit Parameters :
T = 305 K
I0 = 2845
d_{20}/d_{10} = 0.7943
Linewidths = [1.84, 1.322]
Delta = 3.879
E1 = 1787
```