

2-spin

AFM

Heisenberg Model

标准模型

$$H = J \sum_{<i,j>} \mathbf{S}_i \cdot \mathbf{S}_j \quad (1)$$

展开 : $H = J \sum (S_i^x S_j^x + S_i^y S_j^y + S_i^z S_j^z)$

Using a basis $\{| \uparrow\uparrow \rangle, | \uparrow\downarrow \rangle, | \downarrow\uparrow \rangle, | \downarrow\downarrow \rangle\}$ for two spins the matrix representation of one 2-spin term is

$$\begin{pmatrix} J_{ij}/4 & 0 & 0 & 0 \\ 0 & -J_{ij}/4 & J_{ij}/2 & 0 \\ 0 & J_{ij}/2 & -J_{ij}/4 & 0 \\ 0 & 0 & 0 & J_{ij}/4 \end{pmatrix}. \quad (4.5)$$

H

4x4 double

	1	2	3	4
1	0.2500	0	0	0
2	0	-0.2500	0.5000	0
3	0	0.5000	-0.2500	0
4	0	0	0	0.2500

D

4x4 double

	1	2	3	4
1	-0.7500	0	0	0
2	0	0.2500	0	0
3	0	0	0.2500	0
4	0	0	0	0.2500

GS =

0
0.7071
-0.7071
0

FM

4x4 double

	1	2	3	4
1	-0.2500	0	0	0
2	0	-0.2500	0	0
3	0	0	-0.2500	0
4	0	0	0	0.7500

GS =

1
0
0
0

Heisenberg Model

标准模型

$$H = J \sum_{<i,j>} \mathbf{S}_i \cdot \mathbf{S}_j \quad (1)$$

展开 : $H = J \sum (S_i^x S_j^x + S_i^y S_j^y + S_i^z S_j^z)$

2-spin

XXZ model

$$H = \left[\frac{1}{2} (S_1^+ \otimes S_2^- + S_1^- \otimes S_2^+) + \Delta S_1^z \otimes S_2^z \right] \quad (27)$$

% XXZ 参数:
Delta = 1;

AFM

D	1	2	3	4
1	-0.7500	0	0	0
2	0	0.2500	0	0
3	0	0	0.2500	0
4	0	0	0	0.2500

GS	=
0	
0.7071	
-0.7071	
0	

% XXZ 参数:
Delta = 0.5;

% XXZ 参数:
Delta = 2.0;

D	1	2	3	4
1	-0.6250	0	0	0
2	0	0.1250	0	0
3	0	0	0.1250	0
4	0	0	0	0.3750

D	1	GS	GS
1	0		
2	0.7071		
3	-0.7071		
4	0		

D	1	2	3	4
1	-1	0	0	0
2	0	0	0	0
3	0	0	0.5000	0
4	0	0	0	0.5000

GS	1
1	0
2	0.7071
3	-0.7071
4	0

XXZ model

$$H = \left[\frac{1}{2} (S_1^+ \otimes S_2^- + S_1^- \otimes S_2^+) + \Delta S_1^z \otimes S_2^z \right] \quad (27)$$

2-spin

% XXZ 参数:
Delta = 1;

AFM

D	x
4x4 double	
1	-0.7500
2	0.2500
3	0.2500
4	0.2500

GS =
0
0.7071
-0.7071
0

% XXZ 参数:
Delta = 1;

FM

D	x
4x4 double	
1	-0.2500
2	0
3	0
4	0.7500

GS =
1
0
0
0

% XXZ 参数:
Delta = 2.0;

D	x
4x4 double	
1	-1
2	0
3	0.5000
4	0.5000

GS	x
4x1 double	
1	0
2	0.7071
3	-0.7071
4	0

% XXZ 参数:
Delta = 2.0;

D	x
4x4 double	
1	-0.5000
2	0
3	0
4	0

GS =
1
0
0
0

% XXZ 参数:
Delta = 0.5;

D	x
4x4 double	
1	-0.6250
2	0.1250
3	0.1250
4	0.3750

D	GS	x
4x1 double		
1	0	
2	0.7071	
3	-0.7071	
4	0	

% XXZ 参数:
Delta = 0.5;

D	x
4x4 double	
1	-0.3750
2	-0.1250
3	-0.1250
4	0.6250

GS =
0
-0.7071
-0.7071
0

Heisenberg Model

标准模型

$$H = J \sum_{\langle i,j \rangle} \mathbf{S}_i \cdot \mathbf{S}_j \quad (1)$$

3-spin

H =

$$\begin{array}{c}
 \begin{array}{cc|cc}
 1 & 0 & 0 & 0 \\
 0 & -1 & 2 & 0 \\ \hline
 1 & 0 & 0 & 0 \\
 0 & -1 & 2 & 0 \\ \hline
 \end{array} + \begin{array}{cc|cc}
 0 & 2 & -1 & 0 \\
 0 & 0 & 0 & 1 \\ \hline
 0 & 2 & -1 & 0 \\
 0 & 0 & 0 & 1 \\ \hline
 \end{array} = \begin{array}{cc|cc}
 0 & 2 & 0 & 1 \\
 0 & 0 & 1 & 1 \\ \hline
 0 & 2 & 0 & 1 \\
 0 & 0 & 1 & 1 \\ \hline
 \end{array}
 \end{array}$$

XXZ model Delta=1时同样对得上

8×8 H 矩阵:

$$H_1 = H_{\text{odd}} \otimes I$$

$$\begin{bmatrix} 1 & & \\ -1 & 2 & \\ 2 & -1 & \end{bmatrix} \otimes \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$= \begin{array}{c|ccc|ccc} & \textcircled{1} & \textcircled{2} & \textcircled{3} & \textcircled{4} & \textcircled{5} & \textcircled{6} & \textcircled{7} & \textcircled{8} \\ \textcircled{1} & 1 & 0 & & & & & & \\ \textcircled{2} & 0 & 1 & & & & & & \\ \hline \textcircled{3} & & & -1 & 0 & 2 & 0 & & \\ \textcircled{4} & & & 0 & -1 & 0 & 2 & & \\ \hline \textcircled{5} & & & 2 & 0 & -1 & 0 & & \\ \textcircled{6} & & & 0 & 2 & 0 & -1 & & \\ \hline \textcircled{7} & & & & & & 1 & 0 & \\ \textcircled{8} & & & & & & 0 & 1 & \end{array}$$

$$H_2 = I \otimes H_{\text{odd}}$$

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \otimes \begin{bmatrix} 1 & & \\ -1 & 2 & \\ 2 & -1 & \end{bmatrix}$$

$$= \begin{array}{c|ccc|ccc} & \textcircled{1} & \textcircled{2} & \textcircled{3} & \textcircled{4} & \textcircled{5} & \textcircled{6} & \textcircled{7} & \textcircled{8} \\ \textcircled{1} & 1 & & & & & & & \\ \textcircled{2} & -1 & 2 & & & & & & \\ \textcircled{3} & 2 & -1 & & & & & & \\ \hline \textcircled{4} & & & 1 & & & & & \\ \textcircled{5} & & & & -1 & 2 & & & \\ \textcircled{6} & & & & 2 & -1 & 2 & & \\ \textcircled{7} & & & & & 2 & 0 & & \\ \textcircled{8} & & & & & 0 & 1 & & \end{array}$$

H_1

$$\begin{array}{c|cc|cc|cc} & \textcircled{1} & \textcircled{2} & \textcircled{3} & \textcircled{4} & \textcircled{5} & \textcircled{6} \\ \textcircled{1} & 1 & 0 & & & & \\ \textcircled{2} & 0 & 1 & & & & \\ \hline \textcircled{3} & -1 & 0 & 2 & 0 & & \\ \textcircled{4} & 0 & -1 & 0 & 2 & & \\ \hline \textcircled{5} & 2 & 0 & -1 & 0 & & \\ \textcircled{6} & 0 & 2 & 0 & -1 & & \\ \hline \textcircled{7} & & & 1 & 0 & & \\ \textcircled{8} & & & 0 & 1 & & \end{array} + \begin{array}{c|cc|cc|cc} & \textcircled{1} & \textcircled{2} & \textcircled{3} & \textcircled{4} & \textcircled{5} & \textcircled{6} \\ \textcircled{1} & 1 & 0 & & & & \\ \textcircled{2} & 0 & 1 & & & & \\ \hline \textcircled{3} & 2 & -1 & 2 & & & \\ \textcircled{4} & 0 & 2 & 0 & & & \\ \hline \textcircled{5} & 0 & 0 & 1 & & & \\ \textcircled{6} & 0 & 0 & 0 & & & \\ \hline \textcircled{7} & & & 2 & -1 & & \\ \textcircled{8} & & & 1 & 2 & & \end{array}$$

$$\begin{array}{c|cc|cc|cc} & \textcircled{1} & \textcircled{2} & \textcircled{3} & \textcircled{4} & \textcircled{5} & \textcircled{6} \\ \textcircled{1} & 2 & 0 & & & & \\ \textcircled{2} & 0 & 2 & & & & \\ \hline \textcircled{3} & 2 & -2 & 2 & & & \\ \textcircled{4} & 0 & 2 & 2 & & & \\ \hline \textcircled{5} & 2 & 0 & 0 & & & \\ \textcircled{6} & 2 & -2 & 2 & & & \\ \hline \textcircled{7} & & 2 & 0 & & & \\ \textcircled{8} & & & 2 & & & \end{array}$$

$$H_3: I_2 \otimes S_3^{z,\pm}$$

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \otimes \cdots$$

$$0/0/1 \quad 0/1/0$$

$$\begin{array}{c|cc} 1/0/0 & 0/0/-1 \\ \hline 0/0/1 & 0/1/0 \end{array}$$

$$\begin{array}{c|cc} 1/0/0 & 0/0/-1 \\ \hline 0/0/1 & 0/1/0 \end{array}$$

$$S^+ \otimes I \otimes S^-$$

$$\begin{array}{c|cc} 0 & 0 & 0 \\ \hline 0 & 1 & 0 \\ \hline 0 & 0 & 1 \end{array}$$

$$S^- \otimes I \otimes S^+$$

$$\begin{array}{c|cc} 0 & 0 & 0 \\ \hline 0 & 0 & 1 \\ \hline 0 & 1 & 0 \end{array}$$

$$S^z = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$$

$$S^+ = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}$$

$$S^- = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

$$S^z \otimes I \otimes S^z$$

$$\begin{array}{c|cc} 1 & 0 & 0 \\ \hline 0 & -1 & 0 \\ \hline 0 & 0 & 1 \end{array}$$

H_2

$$\begin{array}{c|cc|cc|cc} & \textcircled{1} & \textcircled{2} & \textcircled{3} & \textcircled{4} & \textcircled{5} & \textcircled{6} \\ \textcircled{1} & 1 & 0 & 0 & 0 & 0 & 0 \\ \textcircled{2} & 0 & -1 & 2 & 0 & 0 & 0 \\ \textcircled{3} & 1 & 0 & 0 & 0 & 0 & 0 \\ \textcircled{4} & 0 & -1 & 2 & 0 & 0 & 0 \\ \textcircled{5} & 0 & 0 & 0 & 1 & 0 & 0 \\ \textcircled{6} & 0 & 0 & 0 & 0 & 1 & 0 \\ \hline \textcircled{7} & 0 & 2 & -1 & 0 & 0 & 0 \\ \textcircled{8} & 0 & 0 & 0 & 1 & 0 & 0 \end{array}$$

H_3

手解

$$\begin{array}{c|cc|cc|cc} & \textcircled{1} & \textcircled{2} & \textcircled{3} & \textcircled{4} & \textcircled{5} & \textcircled{6} \\ \textcircled{1} & 1 & 0 & 0 & 0 & 0 & 0 \\ \textcircled{2} & 0 & -1 & 2 & 0 & 0 & 0 \\ \hline \textcircled{3} & 2 & -1 & 0 & 2 & 0 & 0 \\ \textcircled{4} & 0 & 2 & 0 & 0 & 2 & 0 \\ \hline \textcircled{5} & 0 & 0 & 1 & 0 & 0 & 2 \\ \textcircled{6} & 0 & 0 & 0 & 1 & 0 & 0 \\ \hline \textcircled{7} & 2 & 2 & -1 & 0 & 0 & 0 \\ \textcircled{8} & 2 & 0 & -1 & 0 & 0 & 0 \end{array} + \begin{array}{c|cc|cc|cc} & \textcircled{1} & \textcircled{2} & \textcircled{3} & \textcircled{4} & \textcircled{5} & \textcircled{6} \\ \textcircled{1} & 2 & 0 & 2 & 0 & 0 & 0 \\ \textcircled{2} & 0 & 2 & 0 & 2 & 0 & 0 \\ \hline \textcircled{3} & 2 & -2 & 2 & 0 & 0 & 0 \\ \textcircled{4} & 0 & 2 & 2 & 0 & 0 & 0 \\ \hline \textcircled{5} & 2 & 0 & 0 & 2 & 0 & 0 \\ \textcircled{6} & 2 & -2 & 2 & 0 & 0 & 0 \\ \hline \textcircled{7} & 2 & 0 & 0 & 0 & 2 & 0 \\ \textcircled{8} & 2 & 0 & 0 & 0 & 0 & 2 \end{array}$$

$$\times \frac{J}{4}$$

加入纵场项:

$$H = \left[\frac{1}{2}(S_1^+ \otimes S_2^- + S_1^- \otimes S_2^+) + \Delta S_1^z \otimes S_2^z \right] + h_b(S_1^z \otimes I_2) + h_b(I_1 \otimes S_2^z) \quad (28)$$

2-spin

核对手解形式:

2-spin 手入从物

$$h_b \cdot S_1^z \otimes I_2 + h_b \cdot I_1 \otimes S_2^z$$

$$\frac{1}{4} \times \begin{bmatrix} 1 & -1 & 2 \\ -1 & 2 & -1 \\ 2 & -1 & 1 \end{bmatrix} + \begin{bmatrix} h_b & & \\ & h_b & \\ & -h_b & -h_b \end{bmatrix} + \begin{bmatrix} h_b & -h_b & h_b \\ -h_b & h_b & -h_b \\ h_b & -h_b & h_b \end{bmatrix}$$

$$\frac{1}{4} \times \begin{bmatrix} -2h_b & 0 & 0 \\ 0 & 0 & -2h_b \end{bmatrix} \times \frac{1}{2} \xrightarrow{(\sigma \rightarrow S)} \begin{bmatrix} h_b & 0 & 0 \\ 0 & 0 & -h_b \end{bmatrix} \checkmark$$

(用 σ 表示)

$$\frac{1}{4} - 1 = -\frac{3}{4}$$

H				
4x4 double				
1	2	3	4	
1	0.5000	0	0	0
2	0	-0.2500	0.5000	0
3	0	0.5000	-0.2500	0
4	0	0	0	0

H = 4*H;

H				
4x4 double				
1	2	3	4	
1	2	0	0	0
2	0	-1	2	0
3	0	2	-1	0
4	0	0	0	0

对得上

说明一下手解形式: 最左边矩阵是无纵场且提出J/4的,

只有打勾的纵场矩阵是用S矩阵的正确表示 (意味着比sigma矩阵表示差1/2倍)

然后令h=1/4,两个相加之后乘上4倍 (把J/4这项消掉, 矩阵元就是整数加减方便看)

纵场的检验： 3-spin

	1	2	3	4	5	6	7	8
1	1.5000	0	0	0	0	0	0	0
2	0	0	0.5000	0	0.5000	0	0	0
3	0	0.5000	0	0	0.5000	0	0	0
4	0	0	0	-0.5000	0	0.5000	0.5000	0
5	0	0.5000	0.5000	0	0	0	0	0
6	0	0	0	0.5000	0	-0.5000	0.5000	0
7	0	0	0	0.5000	0	0.5000	-0.5000	0
8	0	0	0	0	0	0	0	0

H = 4*H;

也能对上

H X

8x8 double

	1	2	3	4	5	6	7	8
1	6	0	0	0	0	0	0	0
2	0	0	2	0	2	0	0	0
3	0	2	0	0	2	0	0	0
4	0	0	0	-2	0	2	2	0
5	0	2	2	0	0	0	0	0
6	0	0	0	2	0	-2	2	0
7	0	0	0	2	0	2	-2	0
8	0	0	0	0	0	0	0	0

$\begin{matrix} 3 & 0 \\ 0 & -1 & 2 \end{matrix}$	$\begin{matrix} 2 \\ 2 \\ 0 & -1 \end{matrix}$	$\begin{matrix} 2 \\ 2 \\ -1 & 0 \end{matrix}$	$\begin{matrix} 2 \\ 2 \\ 2 & -1 \end{matrix}$
$\begin{matrix} 2 \\ 2 \end{matrix}$	$\begin{matrix} 2 \\ 2 \end{matrix}$	$\begin{matrix} 2 \\ 2 \end{matrix}$	$\begin{matrix} 3 \\ \times \frac{1}{4} \end{matrix}$
$\begin{matrix} 2 \\ 2 \end{matrix}$	$\begin{matrix} 2 \\ 2 \end{matrix}$	$\begin{matrix} 2 \\ 2 \end{matrix}$	$\begin{matrix} 3 \\ \times \frac{1}{4} \end{matrix}$

$$\begin{bmatrix} h_b \\ h_b \\ -h_b \\ -h_b \end{bmatrix} \otimes I_3$$

	1	2	3	4	5	6	7	8
1	h_b							
2		h_b						
3			h_b					
4				h_b				
5					$-h_b$			
6						$-h_b$		
7							$-h_b$	
8								$-h_b$

$$\left[\begin{array}{cccc} h_b & -h_b & h_b & -h_b \\ -h_b & h_b & -h_b & h_b \end{array} \right] \otimes I_3$$

$$I_1 \otimes I_2 \otimes S_3^z$$

三项加起来：纵向项：

<u>6</u>	0			
0	2	2		
2	0	2		
	0	2	2	
2	2	0		
	2	0	2	
	2	2	2	

A coordinate grid with horizontal and vertical axes. The origin is labeled with a small circle. To the right of the origin, along the positive x-axis, there is a point labeled h . To the left of the origin, along the negative x-axis, there is a point labeled $-h$. Further to the left, along the negative x-axis, there is a point labeled -1 .

A coordinate plane with a grid of blue dots. The x-axis is labeled with $-3h$. The y-axis has tick marks at $-3h$, $-2h$, $-1h$, 0 , $1h$, $2h$, and $3h$.

→ S^z 表示向量 $\times \frac{1}{2}$
代码上已经是用 S^z 表示的
所以核对 σ^z 形式时要手动

<u>6</u>	0		
0	<u>0</u>	2	2
2	<u>0</u>	0	2
0	<u>-2</u>	2	2
2	2	<u>0</u>	0
	2	0	<u>-2</u>
	2	2	<u>-2</u>

$$+ b = \frac{1}{4} \times \frac{1}{2} \times 4$$

代入向量关系

$\times 2$

横场Ising:

$$H = \sum_{\langle i,j \rangle} J_{i,j} \sigma_i^z \sigma_j^z - \Gamma \sum_i \sigma_i^x \quad (9)$$

横场的检验： 2/3-spin

>> sgamma

sgamma =

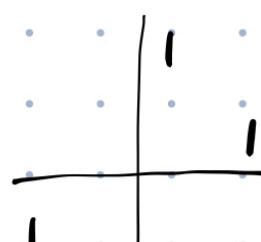
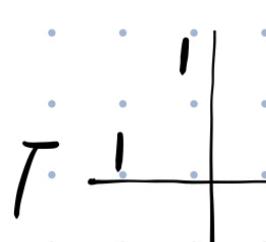
0	1	1	0
1	0	0	1
1	0	0	1
0	1	1	0

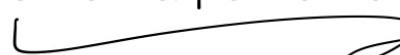
>> sgamma

sgamma =

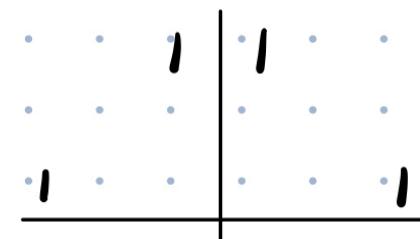
0	1	1	0	1	0	0	0
1	0	0	1	0	1	0	0
1	0	0	1	0	0	1	0
0	1	1	0	0	0	0	1
1	0	0	0	0	1	1	0
0	1	0	0	1	0	0	1
0	0	1	0	1	0	0	1
0	0	0	1	0	1	1	0

$$\Gamma \sigma_1^x \otimes I_2 + \Gamma I_1 \otimes \sigma_2^x$$

$+ \Gamma$  $+ \Gamma$ 



 $+ \downarrow$

Γ 

8×8 横向矩阵：

$$T \sigma_1^x \otimes I_2 \otimes I_3$$

$$\Gamma \vdash_1 \otimes \sigma_2^x \otimes \vdash_3$$

$$T I_1 \otimes I_2 \otimes \sigma_3^x$$

A 10x10 grid with 10 blue dots at the intersections of the 11th and 12th columns. The grid contains 10 vertical bars, each consisting of a short vertical segment and a long horizontal segment extending from its top or bottom.

橫場Ising:

$$H = \sum_{\langle i,j \rangle} J_{i,j} \sigma_i^z \sigma_j^z - \Gamma \sum_i \sigma_i^x \quad (9)$$

2-spin

$$H =$$

1	1	1	0
1	-1	0	1
1	0	-1	1
0	1	1	1

$$\text{Ising} = J \sigma_1^z \otimes \sigma_2^z$$

$$\begin{array}{c} \text{Ising: } \\ \text{2-spin} \end{array} \quad \begin{array}{c} J \\ + \\ 0 \end{array} \quad \begin{array}{c} 1 \\ -1 \\ 0 \\ -1 \end{array}$$

$$+ \Gamma \quad \begin{array}{c} 1 \\ 1 \\ 1 \\ 1 \end{array}$$

$$J = \Gamma = 1 \text{ if:}$$

$$\begin{array}{c} 1 \quad 1 \quad 1 \quad 0 \\ 1 \quad -1 \quad 0 \quad 1 \\ 1 \quad 0 \quad -1 \quad 1 \\ 0 \quad 1 \quad 1 \quad 1 \end{array}$$

橫場Ising model

3-spin

$$H = \sum_{\langle i,j \rangle} J_{ij} \sigma_i^z \sigma_j^z - \Gamma \sum_i \sigma_i^x.$$

H =							
3	1	1	0	1	0	0	0
1	-1	0	1	0	1	0	0
1	0	-1	1	0	0	1	0
0	1	1	-1	0	0	0	1
1	0	0	0	-1	1	1	0
0	1	0	0	1	-1	0	1
0	0	1	0	1	0	-1	1
0	0	0	1	0	1	1	3

8x8矩阵的Ising只是Heisenberg矩阵的对角元（不乘上1/4系数），

此时再把横场加上，矩阵如左表示

4-spin

From https://colab.research.google.com/github/hylu666/hku-physics4150/blob/main/ED/ED_Heisenberg.ipynb#scrollTo=qPJhfmZQgAHz

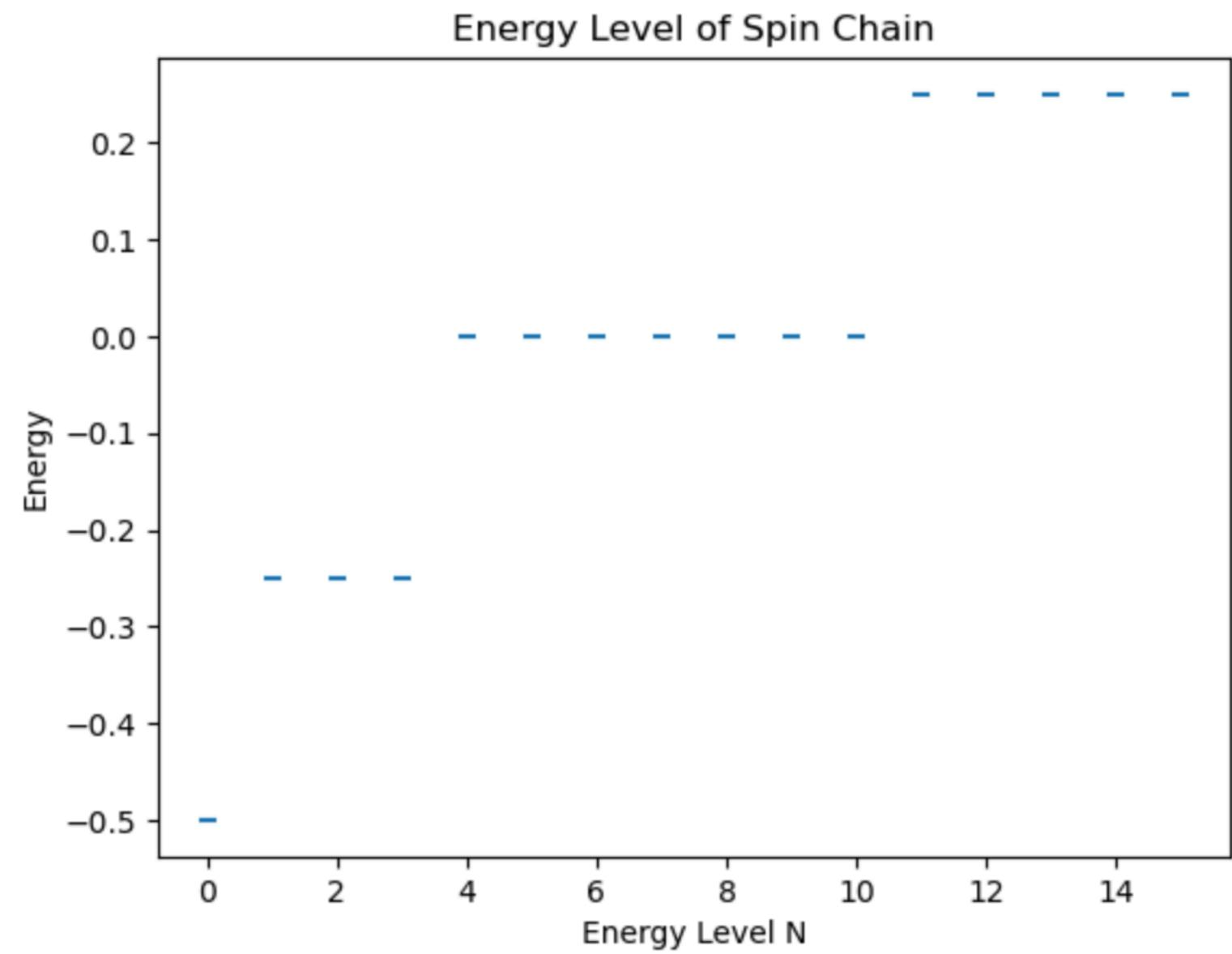
```
([[1., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
 [0., 0., 0.5, 0., 0., 0., 0., 0.5, 0., 0., 0., 0., 0., 0., 0., 0.],
 [0., 0.5, 0., 0., 0.5, 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
 [0., 0., 0., 0., 0.5, 0., 0., 0., 0., 0., 0.5, 0., 0., 0., 0., 0.],
 [0., 0., 0.5, 0., 0., 0., 0., 0.5, 0., 0., 0., 0., 0., 0., 0., 0.],
 [0., 0., 0.5, 0., -1., 0.5, 0., 0., 0.5, 0., 0., 0., 0., 0., 0., 0.]
 [0., 0., 0., 0., 0.5, 0., 0., 0., 0., 0., 0.5, 0., 0., 0., 0., 0.],
 [0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.5, 0., 0., 0.5, 0., 0.],
 [0., 0.5, 0., 0., 0.5, 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.],
 [0., 0., 0., 0., 0.5, 0., 0., 0., 0., 0., 0.5, 0., 0., 0., 0., 0.],
 [0., 0., 0.5, 0., 0., 0.5, 0., 0., 0.5, -1., 0., 0.5, 0., 0., 0., 0.]
 [0., 0., 0., 0., 0., 0.5, 0., 0., 0., 0., 0., 0., 0., 0.5, 0., 0.],
 [0., 0., 0., 0., 0.5, 0., 0., 0., 0., 0., 0.5, 0., 0., 0., 0., 0.],
 [0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.5, 0., 0., 0.5, 0., 0.],
 [0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.5, 0., 0., 0.5, 0., 0.],
 [0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0., 0.5, 0., 0., 0.5, 0.]]))
```

哈密顿量矩阵

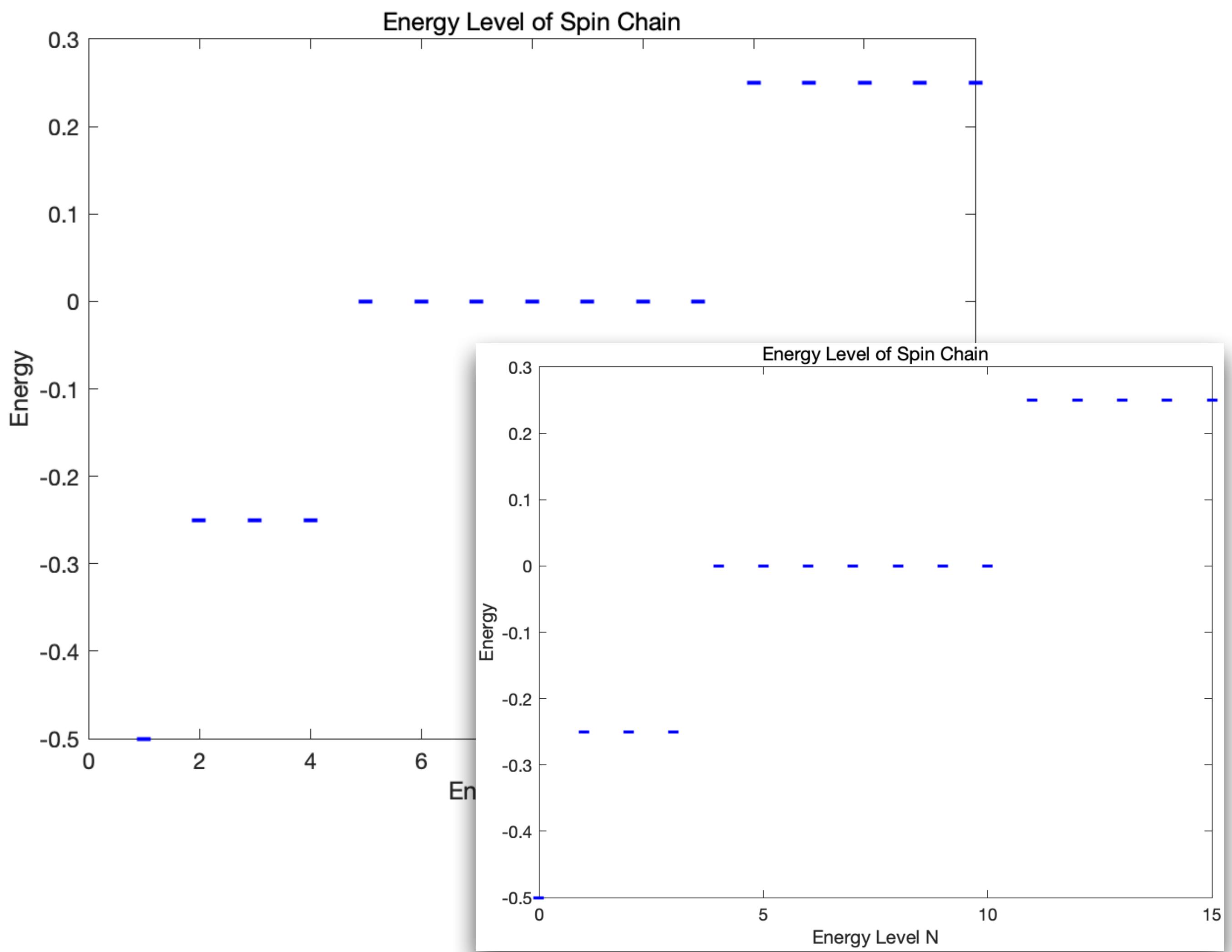
Python (来自于别人的ED python) 和自己的MATLAB

能够对上

能级有些微的不同



plot数据from 上页



调整横坐标取值之后对上了

我怀疑是MATLAB和Python对哈密顿量矩阵的对角化处理会有点不一样

我分别尝试了，将相同的哈密顿量引入MATLAB和python（其中通过csv这个文件导入由MATLAB生成的矩阵）

通过各自的对角化，发现确实存在细微的差别

```
python | eig_value=np.real(np.linalg.eig(H)[0])# eigen_values  
eig_vec=np.real(np.linalg.eig(H)[1]) # eigenstates
```

排序后的本征值

```
[-5.0000000e-01 -2.5000000e-01 -2.5000000e-01 -2.5000000e-01  
-3.82580930e-17 -1.41786105e-17 -1.13040275e-33 -5.53653701e-34  
3.16194328e-33 1.35833475e-17 2.42420365e-17 2.50000000e-01  
2.50000000e-01 2.50000000e-01 2.50000000e-01 2.50000000e-01]
```

基态波函数

```
[ 0.0000000e+00 5.54163012e-17 1.09226604e-17 2.88675135e-01  
-1.65708221e-16 -5.77350269e-01 2.88675135e-01 -3.20493781e-17  
1.09226604e-17 2.88675135e-01 -5.77350269e-01 4.95678897e-33  
2.88675135e-01 3.20493781e-17 5.98276725e-33 0.00000000e+00]
```

在数量级~ -17 的差距有些大

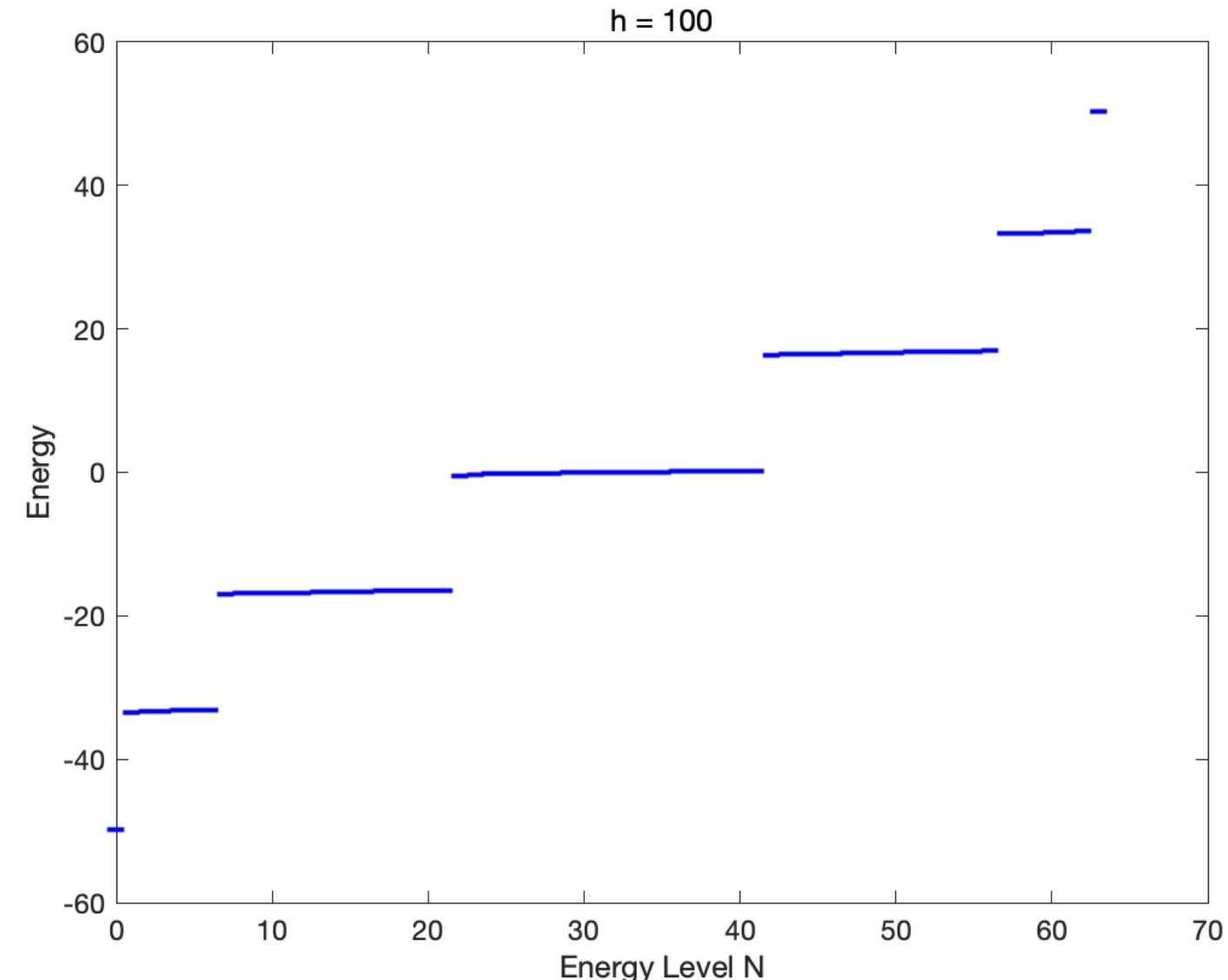
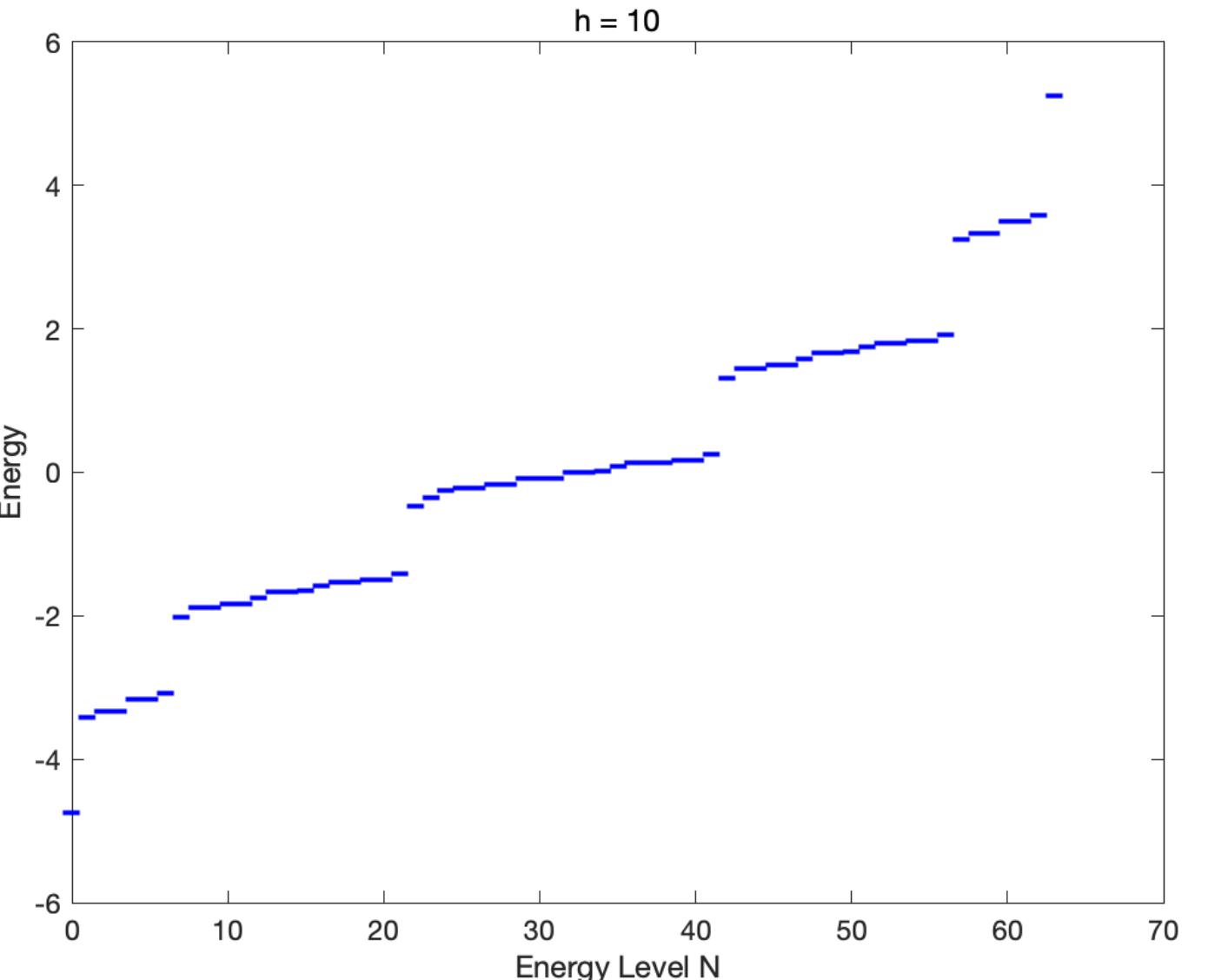
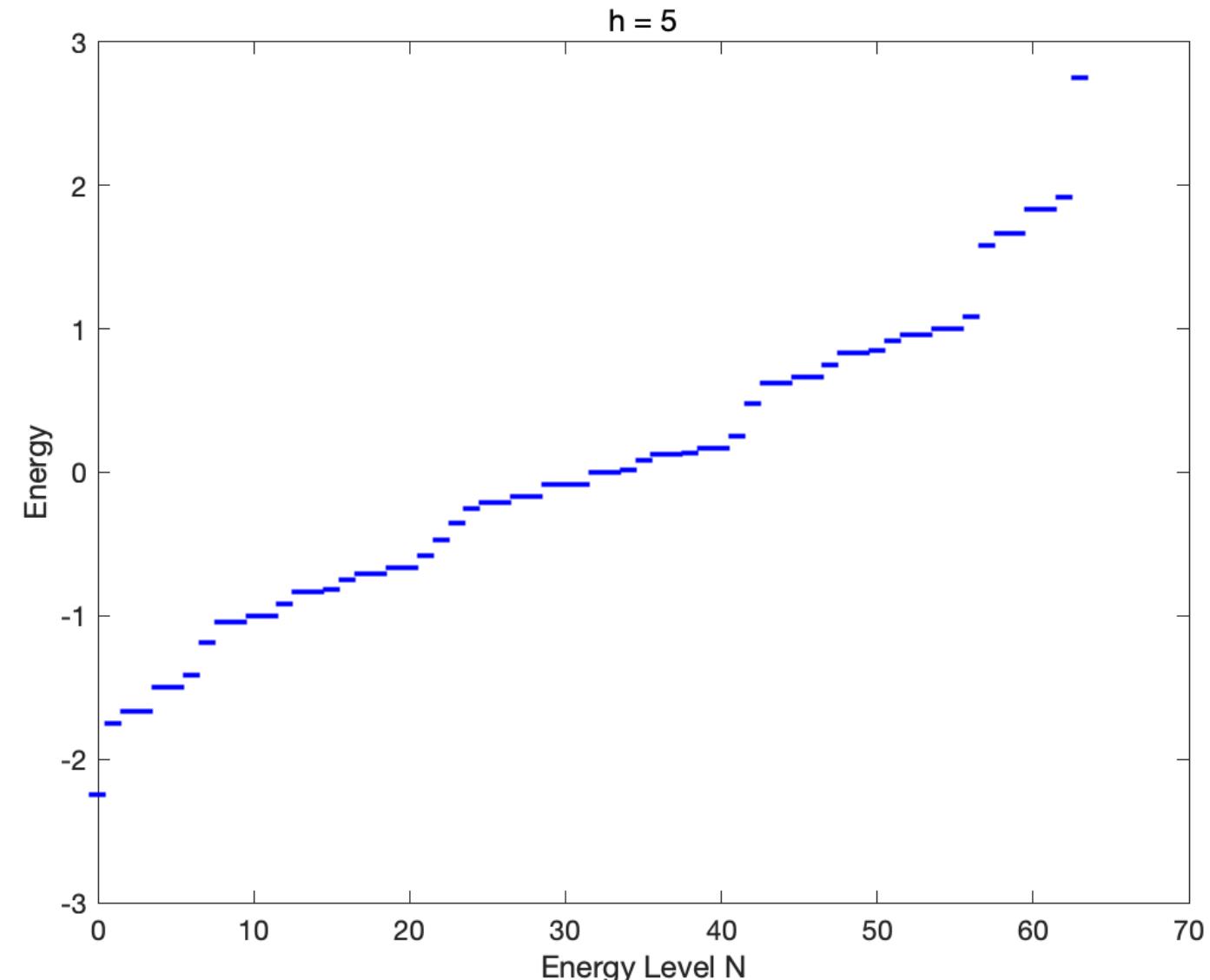
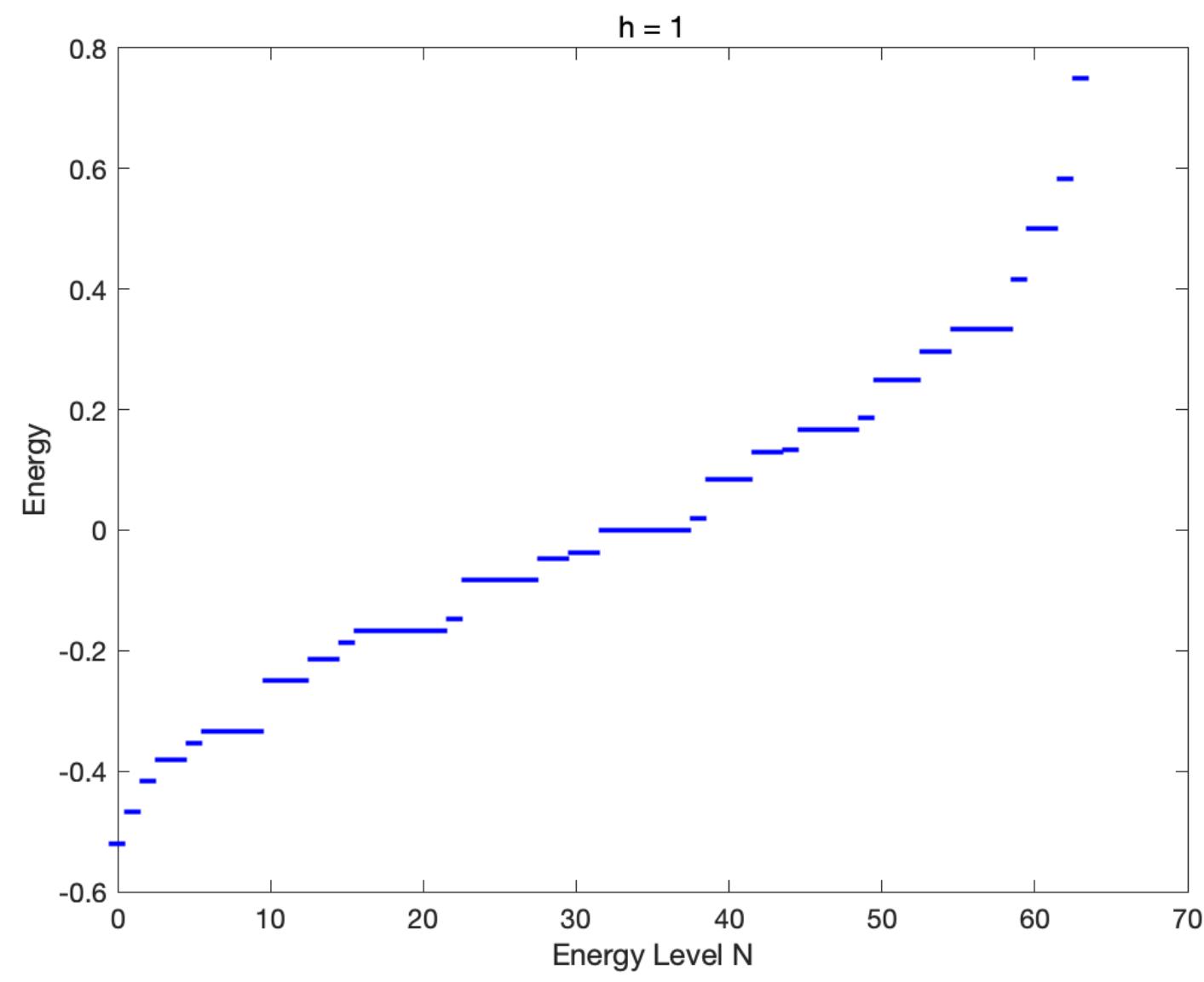
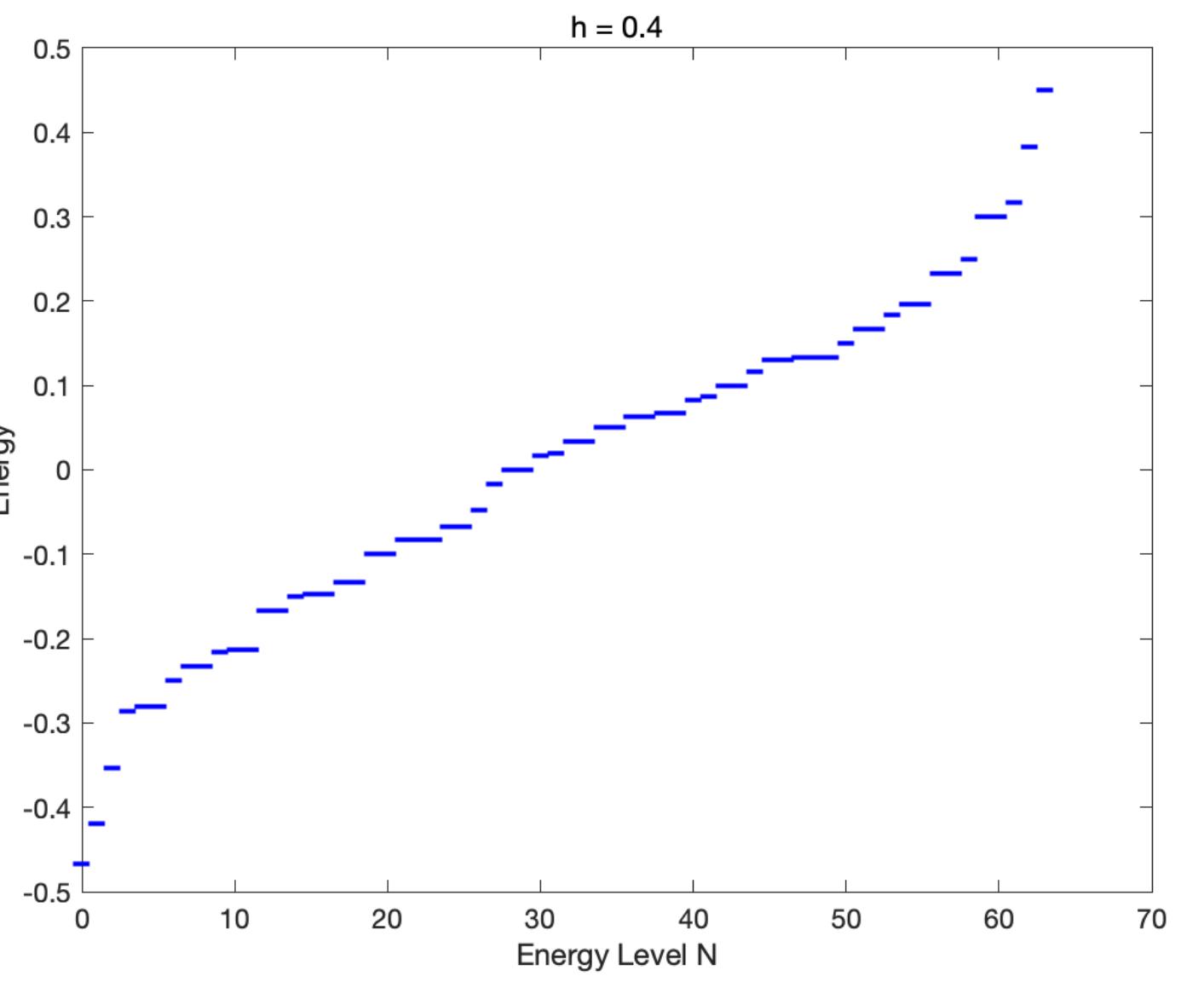
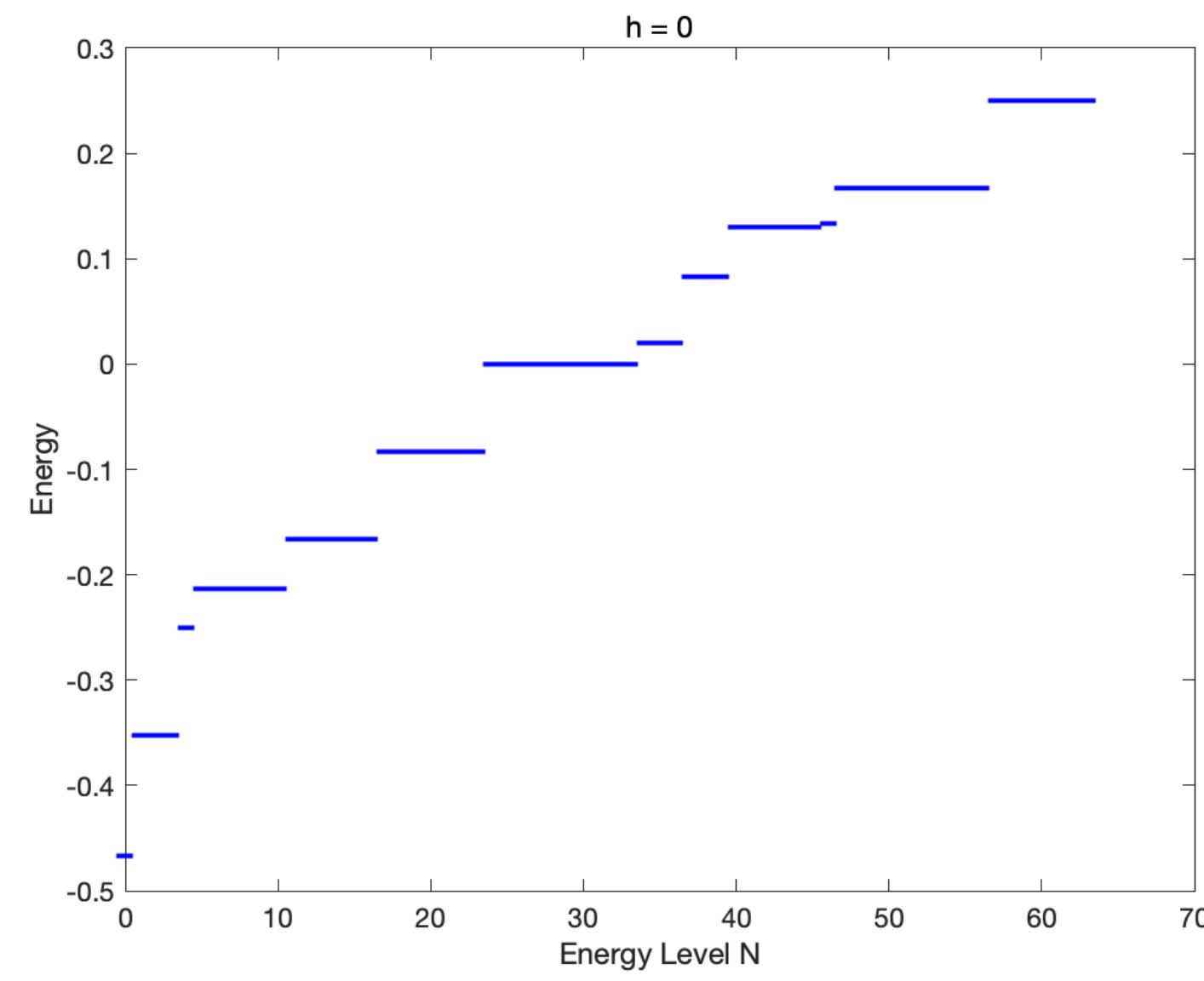
The screenshot shows the MATLAB workspace with two variables: `D` and `GS`. Both are 16×1 double precision arrays. The `D` array contains values: 1, -0.5000, -0.2500, -0.2500, -0.2500, -4.1934e-18, -4.1934e-18, 0, 0, 5.7778e-34, 4.1934e-18, 4.1934e-18, 0.2500, 0.2500, 0.2500, 0.2500, 0.2500. The `GS` array contains values: 1, 0, 0, 0, -0.2887, 0, 0.5774, -0.2887, -6.1915e-17, 0, 0, -0.2887, 0.5774, 0, -0.2887, 6.1915e-17, 0.

	D	GS
1	1	1
2	-0.5000	0
3	-0.2500	0
4	-0.2500	0
5	-0.2500	0
6	-4.1934e-18	-0.2887
7	-4.1934e-18	0
8	0	-0.2887
9	5.7778e-34	-6.1915e-17
10	4.1934e-18	0
11	4.1934e-18	0
12	0.2500	0.5774
13	0.2500	0
14	0.2500	-0.2887
15	0.2500	6.1915e-17
16	0.2500	0

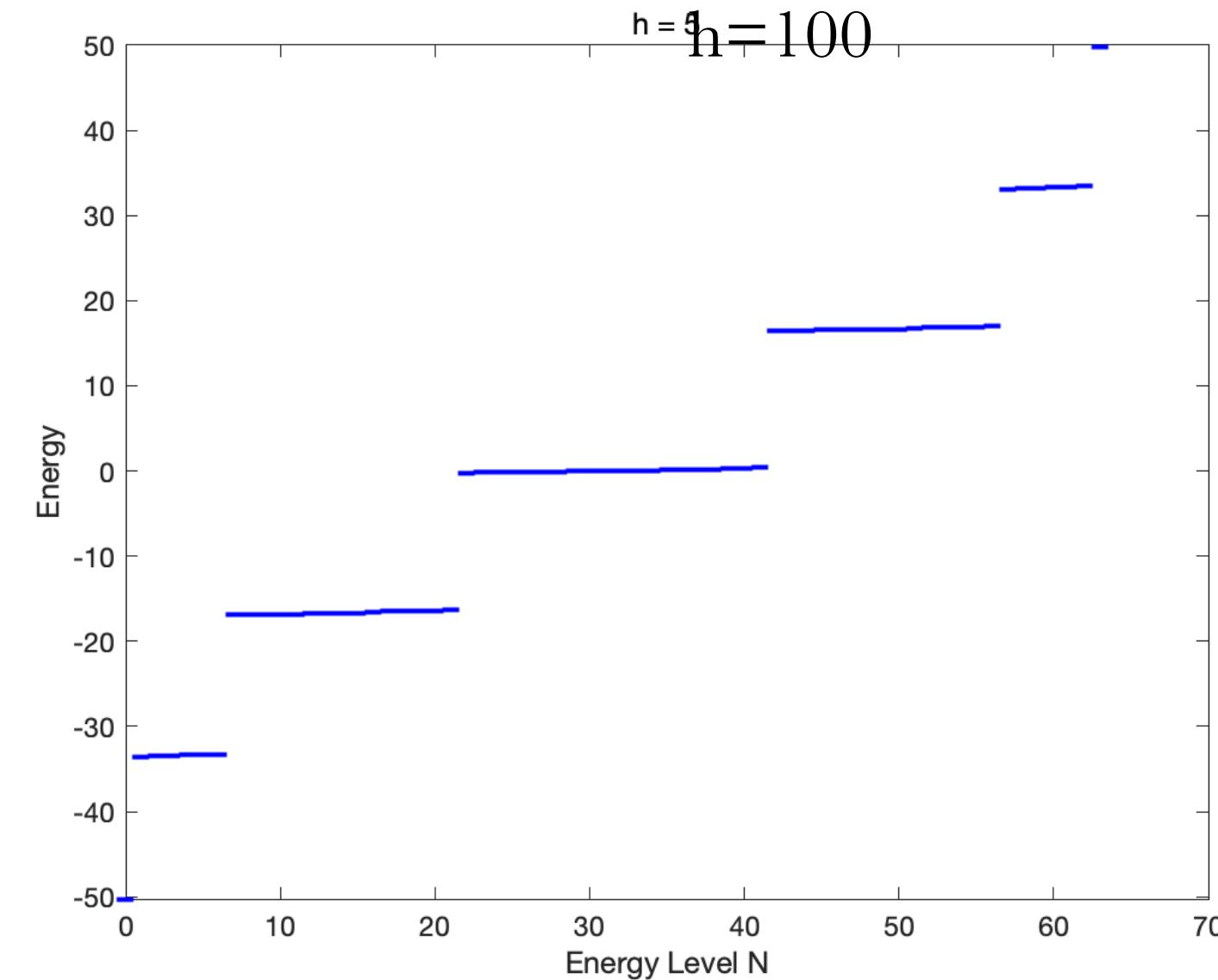
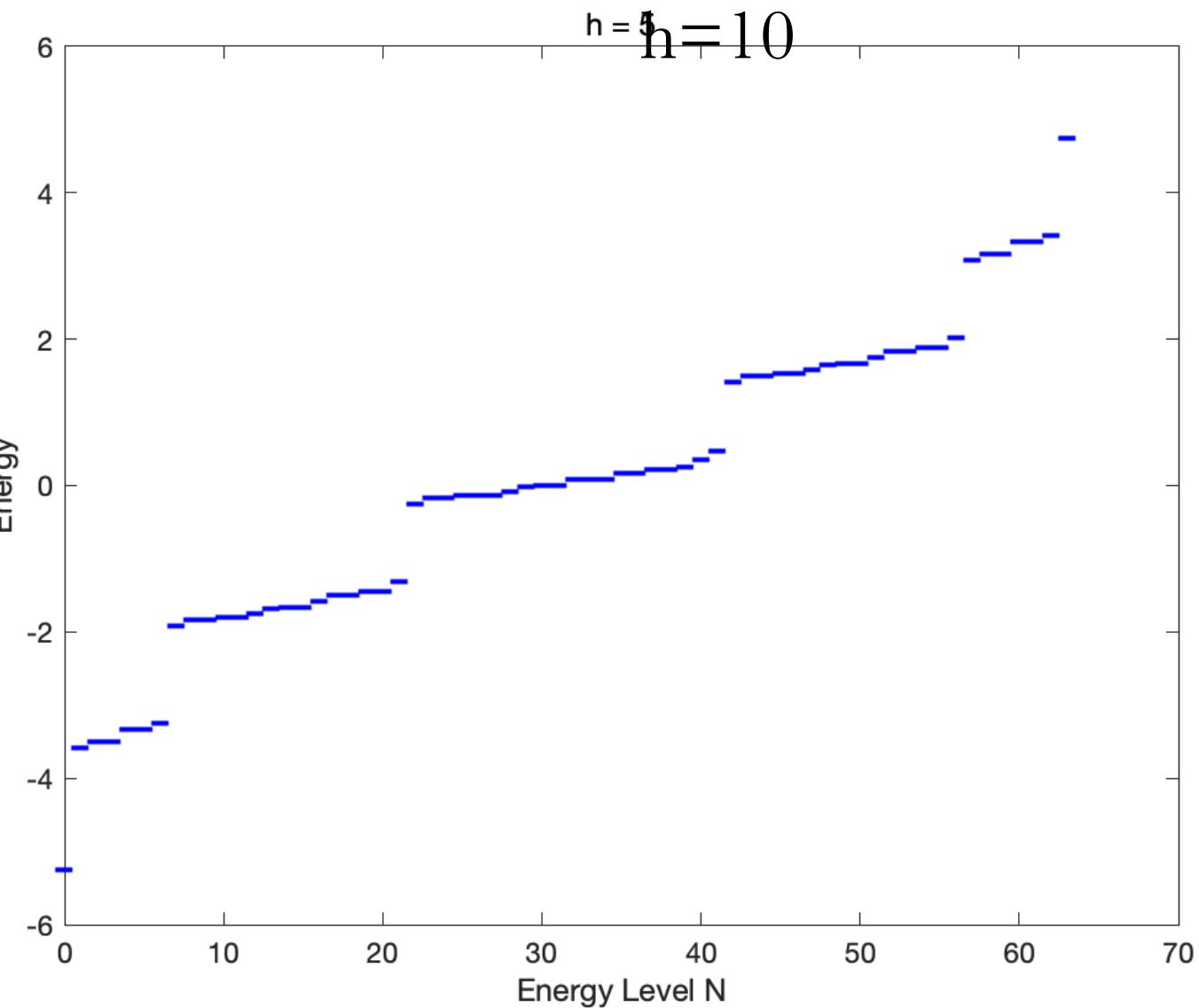
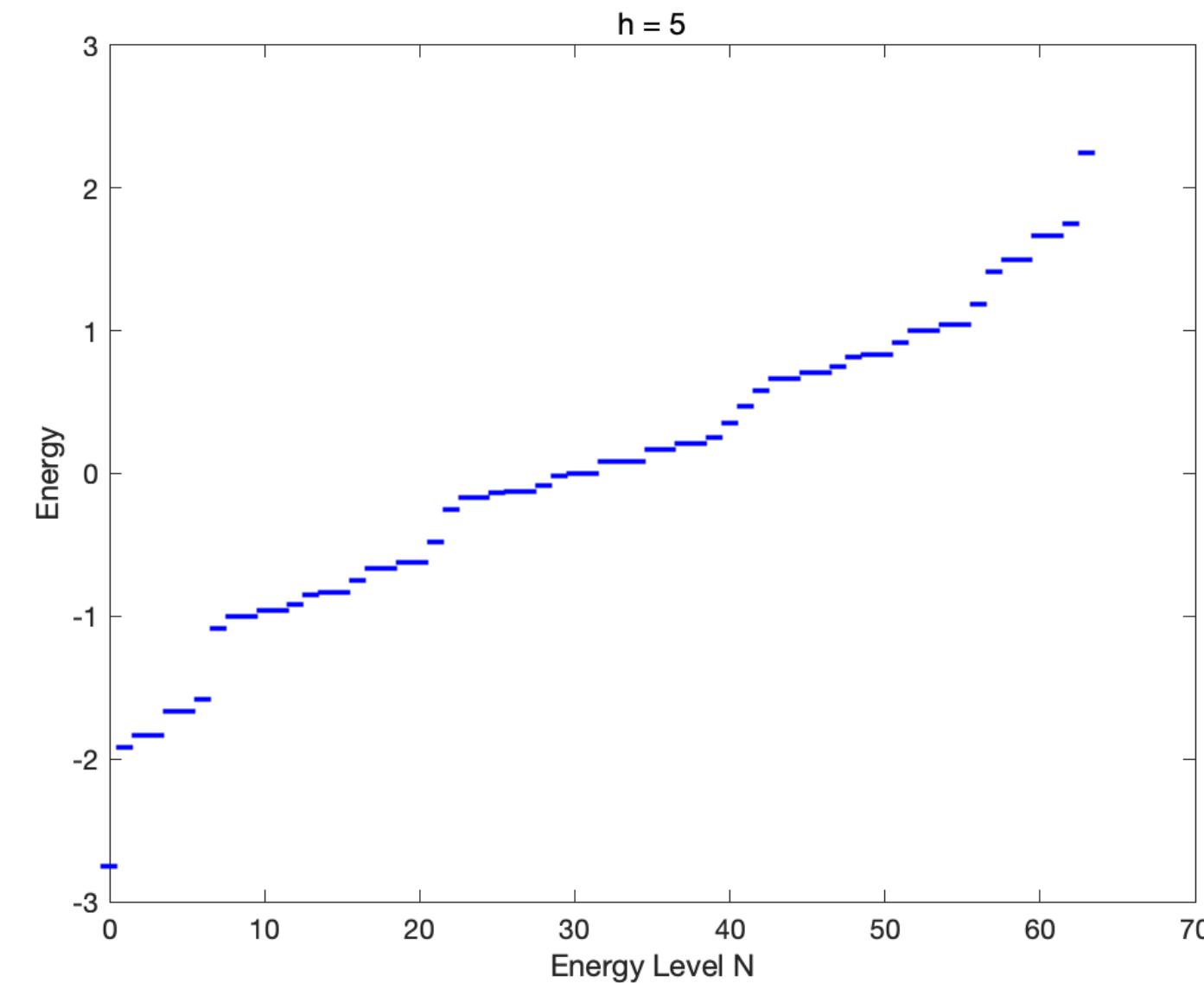
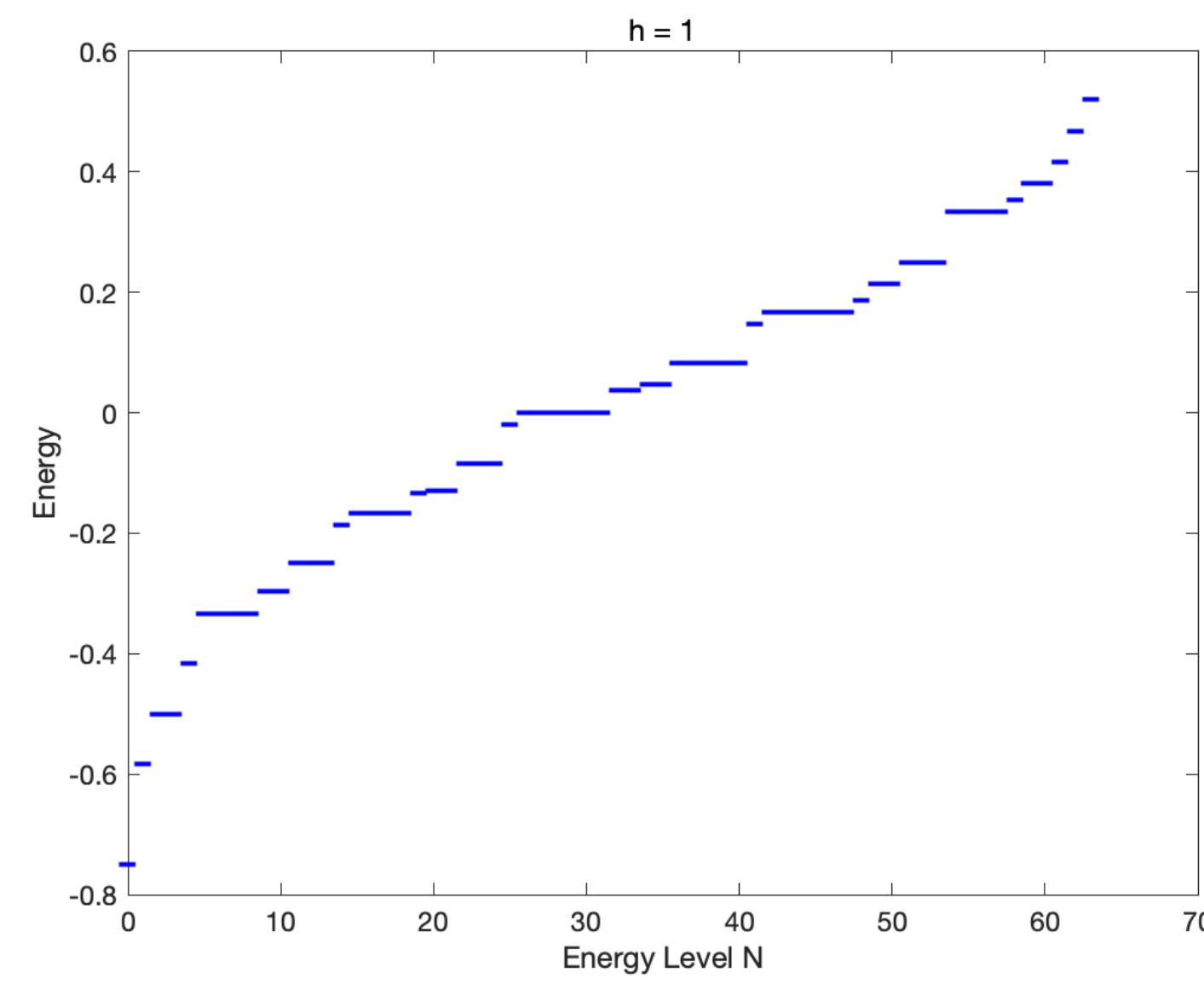
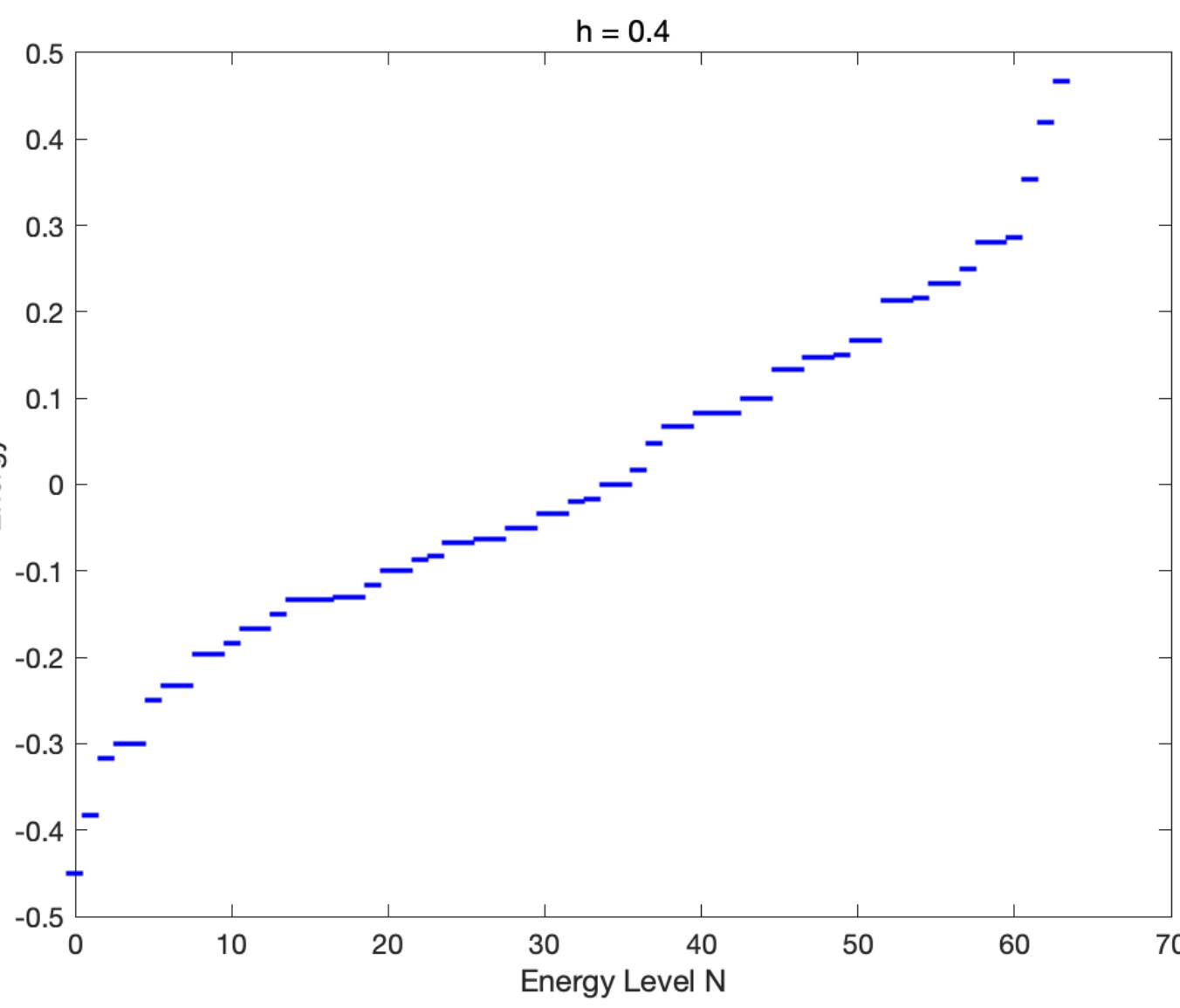
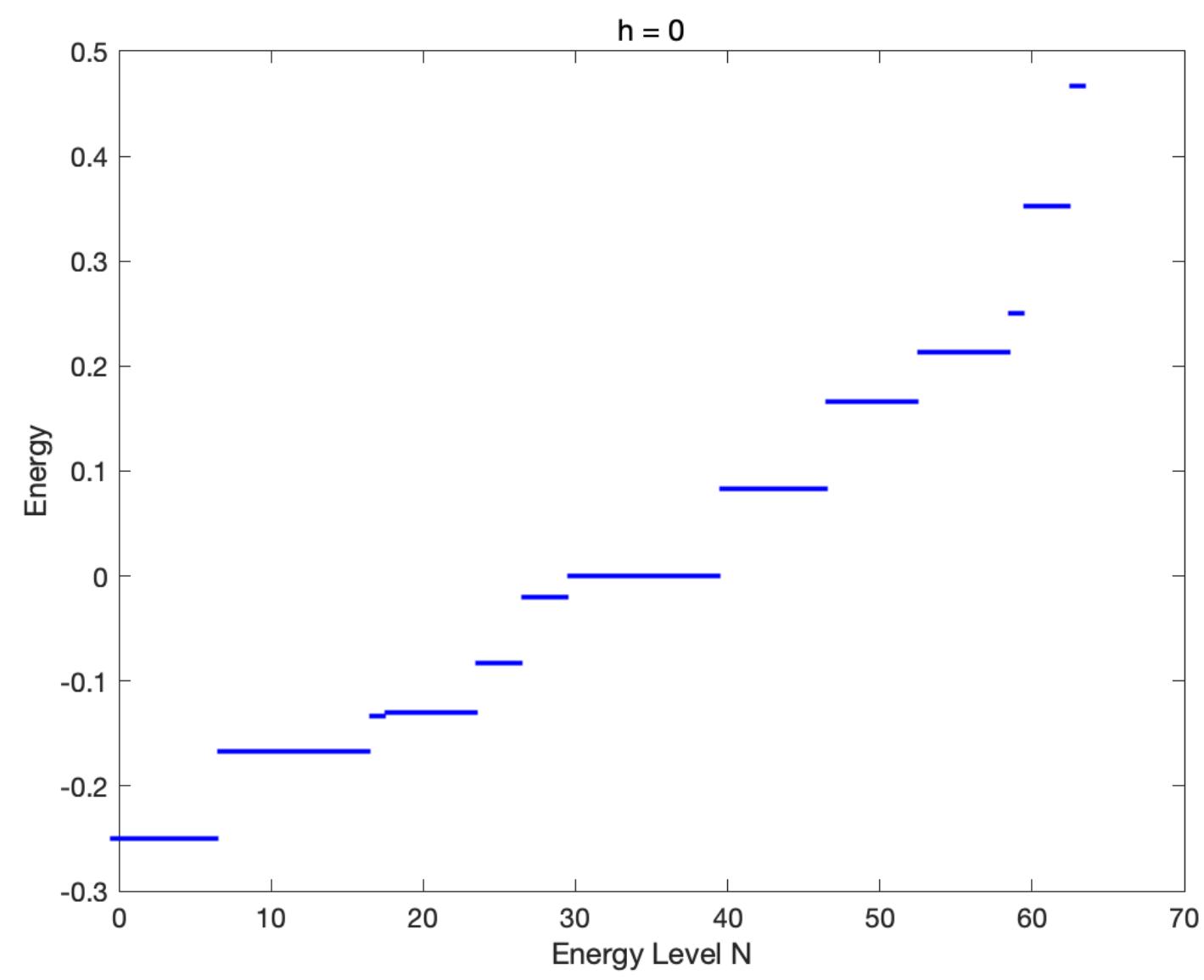
加上纵场的能级

6-spin

AFM +/- h



FM +/- h



绘制的代码：

```
[V,D] = eig(H);
% det(H)
D = diag(D)/L
GS=V(:,1) % gound state

GSE = min(D)

% Plotting Energy Level of Spin Chain
energy_level = D; % Assuming the division by 4 is required for the plot
figure;
plot(0:length(energy_level)-1, energy_level, '_','Color', 'blue', 'LineWidth', 2);
xlabel('Energy Level N');
ylabel('Energy');
title('h = 0');
```