Anexo

En este anexo aparecen los códigos de mathematica utilizados para hacer los cálculos del trabajo “Optimización de observables cuánticos para la maximización de la visibilidad de la autocorrelación”.

Los distintos ficheros de mathemática aparecen nombrados y ordenados por correspondencia a las secciones del trabajo principal:

Secciones del anexo
3.1.- S=1/2 - Heisenberg
3.2.- S=1 - Heisenberg
3.3.- S=9/2 - Heisenberg
4.1.1.- S=0.5 con pérdidas - Schrödinger
4.1.2.- S=0.5 con pérdidas - Heisenberg
4.2.1.- S=0.5 con ganancias - Schrödinger
4.2.2.- S=0.5 con ganancias - Heisenberg
4.3.1.- S=0.5 con pérdidas y ganancias - Schrödinger
4.3.2.- S=0.5 con pérdidas y ganancias - Heisenberg
4.4.1.- S=0.5 con defasaje - Schrödinger
4.4.2.- S=0.5 con defasaje - Heisenberg
4.5.1.- S=0.5 con pérdidas, ganancias y defasaje - Schrödinger
4.5.2.- S=0.5 con pérdidas, ganancias y defasaje - Heisenberg
4.5.2.- Manipulable 6 parámetros

Estos ficheros se encuentran adjuntos al trabajo principal en la plataforma ADDI. Entre ellos, el fichero `4.5.2.- Manipulable 6 parámetros.nb` contiene un gráfico interactivo en el que se pueden manipular lor parámetros del sistema. El programa arroja el gráfico que, con los parámetros escogidos, cumple el requisito impuesto de $|C(t)|_{min} = 0$.

3.1.- S=1/2 - Heisenberg

In[∘]:=
```
S0 = {{1, 0}, {0, 1}} ; (*Identidad 2x2*)
Sx = {{0, 1}, {1, 0}} ; (*Sigma x*)
Sy = {{0, -I}, {I, 0}} ;
Sz = {{1, 0}, {0, -1}} ;

H2 = {{w1, 0}, {0, w2}}; (*Hamiltoniano 2x2*)

U2 = {{Exp[-I w1 t], 0}, {0, Exp[-I w2 t]}};
U2dg = {{Exp[I w1 t], 0}, {0, Exp[I w2 t]}};
Ro2 = 1/Z {{Exp[-b w1], 0}, {0, Exp[-b w2]}};
```

In[∘]:=
```
S = {S0, Sx, Sy, Sz} ;
```

In[∘]:=
```
Do[{Print[ Subscript["A", n], "(t)=" ,
   Simplify[MatrixForm[ExpToTrig[U2dg.S[[n + 1]].U2]]]]}, {n, 0, 3}]
 (* los índices del vector en mathematica van del 1 al 4, de ahí el n+1 *)
```

$$A_0(t) = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$A_1(t) = \begin{pmatrix} 0 & \text{Cos}[t(w_1 - w_2)] + i\,\text{Sin}[t(w_1 - w_2)] \\ \text{Cos}[t(w_1 - w_2)] - i\,\text{Sin}[t(w_1 - w_2)] & 0 \end{pmatrix}$$

$$A_2(t) = \begin{pmatrix} 0 & -i\,\text{Cos}[t(w_1 - w_2)] + \text{Sin}[t(w_1 - w_2)] \\ i\,\text{Cos}[t(w_1 - w_2)] + \text{Sin}[t(w_1 - w_2)] & 0 \end{pmatrix}$$

$$A_3(t) = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

In[∘]:=
```
Do[Do[Print["<", Subscript["A", n], "(0)", Subscript["A", m], "(t)",
   "> = ", Tr[Ro2.U2dg.S[[n + 1]].U2.S[[m + 1]]]], {n, 0, 3}], {m, 0, 3}]
(* los índices del vector en mathematica van del 1 al 4,
de ahí el n+1 y el m+1 *)
```

$$<A_0(0)A_0(t)> \;=\; \frac{e^{-b\,w_1}}{Z} + \frac{e^{-b\,w_2}}{Z}$$

$$<A_1(0)A_0(t)> \;=\; 0$$

$$<A_2(0)A_0(t)> \;=\; 0$$

$$<A_3(0)A_0(t)> \;=\; \frac{e^{-b\,w_1}}{Z} - \frac{e^{-b\,w_2}}{Z}$$

$$<A_0(0)A_1(t)> \;=\; 0$$

$$<A_1(0)A_1(t)> \;=\; \frac{e^{-b\,w_1+i\,t\,w_1-i\,t\,w_2}}{Z} + \frac{e^{-i\,t\,w_1-b\,w_2+i\,t\,w_2}}{Z}$$

$$<A_2(0)A_1(t)> \;=\; -\frac{i\,e^{-b\,w_1+i\,t\,w_1-i\,t\,w_2}}{Z} + \frac{i\,e^{-i\,t\,w_1-b\,w_2+i\,t\,w_2}}{Z}$$

$$<A_3(0)A_1(t)> \;=\; 0$$

$$<A_0(0)A_2(t)> \;=\; 0$$

$$<A_1(0)A_2(t)> \;=\; \frac{i\,e^{-b\,w_1+i\,t\,w_1-i\,t\,w_2}}{Z} - \frac{i\,e^{-i\,t\,w_1-b\,w_2+i\,t\,w_2}}{Z}$$

$$<A_2(0)A_2(t)> \;=\; \frac{e^{-b\,w_1+i\,t\,w_1-i\,t\,w_2}}{Z} + \frac{e^{-i\,t\,w_1-b\,w_2+i\,t\,w_2}}{Z}$$

$$<A_3(0)A_2(t)> \;=\; 0$$

$$<A_0(0)A_3(t)> \;=\; \frac{e^{-b\,w_1}}{Z} - \frac{e^{-b\,w_2}}{Z}$$

$$<A_1(0)A_3(t)> \;=\; 0$$

$$<A_2(0)A_3(t)> \;=\; 0$$

$$<A_3(0)A_3(t)> \;=\; \frac{e^{-b\,w_1}}{Z} + \frac{e^{-b\,w_2}}{Z}$$

In[ ]:=

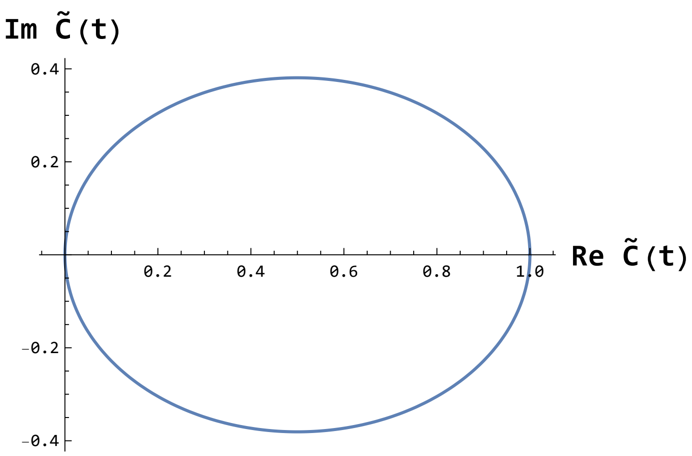
$$C2[t\_] = \left(\frac{e^{-3+3\,i\,t-i\,t}}{e^{-3}+e^{-1}} + \frac{e^{-1-3\,i\,t+i\,t}}{e^{-3}+e^{-1}}\right) + (1) \;\; \text{(*Correlación } \tfrac{1}{2}\text{A1+}\tfrac{1}{2}\text{A3 para w1=3, w2=1, b=1*)}$$

$$\text{ParametricPlot}\left[\left\{\text{Re}\left[\frac{C2[t]}{C2[0]}\right], \text{Im}\left[\frac{C2[t]}{C2[0]}\right]\right\}, \{t, 0, \text{Pi}\},\right.$$
$$\text{AxesLabel} \to \{\text{Style}[\text{"Re }\tilde{C}(t)\text{"}, \text{Bold}, 16], \text{Style}[\text{"Im }\tilde{C}(t)\text{"}, \text{Bold}, 16]\},$$
$$\left.\text{FormatType} \to \text{StandardForm}\right]$$

Out[ ]=

$$1 + \frac{e^{-1-2\,i\,t}}{\frac{1}{e^3}+\frac{1}{e}} + \frac{e^{-3+2\,i\,t}}{\frac{1}{e^3}+\frac{1}{e}}$$

Out[ ]=



3.2.- S=1 - Heisenberg

```
In[ ]:= GM0 = {{1, 0, 0}, {0, 1, 0}, {0, 0, 1}} ; (*IDENTIDAD*)
        GM1 = {{0, 1, 0}, {1, 0, 0}, {0, 0, 0}} ;
        GM2 = {{0, -I, 0}, {I, 0, 0}, {0, 0, 0}} ;
        GM3 = {{1, 0, 0}, {0, -1, 0}, {0, 0, 0}} ;
        GM4 = {{0, 0, 1}, {0, 0, 0}, {1, 0, 0}} ;
        GM5 = {{0, 0, -I}, {0, 0, 0}, {I, 0, 0}} ;
        GM6 = {{0, 0, 0}, {0, 0, 1}, {0, 1, 0}} ;
        GM7 = {{0, 0, 0}, {0, 0, -I}, {0, I, 0}} ;
        GM8 = {{3^(-1/2), 0, 0}, {0, 3^(-1/2), 0}, {0, 0, -2 × 3^(-1/2)}} ;

        H3 = {{w1, 0, 0}, {0, w2, 0}, {0, 0, w3}};

        U3 = {{Exp[-I w1 t], 0, 0}, {0, Exp[-I w2 t], 0}, {0, 0, Exp[-I w3 t]}};
        U3dg = {{Exp[I w1 t], 0, 0}, {0, Exp[I w2 t], 0}, {0, 0, Exp[I w3 t]}};
        Ro3 = 1/Z {{Exp[-b w1], 0, 0}, {0, Exp[-b w2], 0}, {0, 0, Exp[-b w3]}};

In[ ]:= GM = {GM0, GM1, GM2, GM3, GM4, GM5, GM6, GM7, GM8} ;

In[ ]:= Do[{Print[ Subscript["A", n], "(t)=" ,
          Simplify[MatrixForm[ExpToTrig[U3dg.GM[[n + 1]].U3]]]]}, {n, 0, 8}]
        (* los índices de un vector en mathematica van del 1 al 9, de ahí el n+1 *)
```

$$A_0(t) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$A_1(t) = \begin{pmatrix} 0 & \text{Cos}[t\,(w_1 - w_2)] + i\,\text{Sin}[t\,(w_1 - w_2)] & 0 \\ \text{Cos}[t\,(w_1 - w_2)] - i\,\text{Sin}[t\,(w_1 - w_2)] & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$A_2(t) = \begin{pmatrix} 0 & -i\,\text{Cos}[t\,(w_1 - w_2)] + \text{Sin}[t\,(w_1 - w_2)] & 0 \\ i\,\text{Cos}[t\,(w_1 - w_2)] + \text{Sin}[t\,(w_1 - w_2)] & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$A_3(t) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$A_4(t) = \begin{pmatrix} 0 & 0 & \text{Cos}[t\,(w_1 - w_3)] + i\,\text{Sin}[t\,(w_1 - w_3)] \\ 0 & 0 & 0 \\ \text{Cos}[t\,(w_1 - w_3)] - i\,\text{Sin}[t\,(w_1 - w_3)] & 0 & 0 \end{pmatrix}$$

$$A_5(t) = \begin{pmatrix} 0 & 0 & -i\,\text{Cos}[t\,(w_1 - w_3)] + \text{Sin}[t\,(w_1 - w_3)] \\ 0 & 0 & 0 \\ i\,\text{Cos}[t\,(w_1 - w_3)] + \text{Sin}[t\,(w_1 - w_3)] & 0 & 0 \end{pmatrix}$$

$$A_6(t) = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & \text{Cos}[t\,(w_2 - w_3)] + i\,\text{Sin}[t\,(w_2 - w_3)] \\ 0 & \text{Cos}[t\,(w_2 - w_3)] - i\,\text{Sin}[t\,(w_2 - w_3)] & 0 \end{pmatrix}$$

$$A_7(t) = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & -i\,\text{Cos}[t\,(w_2 - w_3)] + \text{Sin}[t\,(w_2 - w_3)] \\ 0 & i\,\text{Cos}[t\,(w_2 - w_3)] + \text{Sin}[t\,(w_2 - w_3)] & 0 \end{pmatrix}$$

$$A_8(t) = \begin{pmatrix} \frac{1}{\sqrt{3}} & 0 & 0 \\ 0 & \frac{1}{\sqrt{3}} & 0 \\ 0 & 0 & -\frac{2}{\sqrt{3}} \end{pmatrix}$$

In[∘]:=

```
Do[Do[Print["<", Subscript["A", n], "(0)", Subscript["A", m], "(t)",
    "> = ", Tr[Ro3.U3dg.GM[[n + 1]].U3.GM[[m + 1]]]], {n, 0, 8}], {m, 0, 8}]
(* los índices de un vector en mathematica van del 1 al 9,
de ahí el n+1 y el m+1 *)
```

$$<A_0(0)A_0(t)> = \frac{e^{-b w_1}}{Z} + \frac{e^{-b w_2}}{Z} + \frac{e^{-b w_3}}{Z}$$

$$<A_1(0)A_0(t)> = 0$$

$$<A_2(0)A_0(t)> = 0$$

$$<A_3(0)A_0(t)> = \frac{e^{-b w_1}}{Z} - \frac{e^{-b w_2}}{Z}$$

$$<A_4(0)A_0(t)> = 0$$

$$<A_5(0)A_0(t)> = 0$$

$$<A_6(0)A_0(t)> = 0$$

$$<A_7(0)A_0(t)> = 0$$

$$<A_8(0)A_0(t)> = \frac{e^{-b w_1}}{\sqrt{3}\, Z} + \frac{e^{-b w_2}}{\sqrt{3}\, Z} - \frac{2\, e^{-b w_3}}{\sqrt{3}\, Z}$$

$$<A_0(0)A_1(t)> = 0$$

$$<A_1(0)A_1(t)> = \frac{e^{-b w_1 + i t w_1 - i t w_2}}{Z} + \frac{e^{-i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_2(0)A_1(t)> = -\frac{i\, e^{-b w_1 + i t w_1 - i t w_2}}{Z} + \frac{i\, e^{-i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_3(0)A_1(t)> = 0$$

$$<A_4(0)A_1(t)> = 0$$

$$<A_5(0)A_1(t)> = 0$$

$$<A_6(0)A_1(t)> = 0$$

$$<A_7(0)A_1(t)> = 0$$

$$<A_8(0)A_1(t)> = 0$$

$$<A_0(0)A_2(t)> = 0$$

$$<A_1(0)A_2(t)> = \frac{i\, e^{-b w_1 + i t w_1 - i t w_2}}{Z} - \frac{i\, e^{-i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_2(0)A_2(t)> = \frac{e^{-b w_1 + i t w_1 - i t w_2}}{Z} + \frac{e^{-i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_3(0)A_2(t)> = 0$$

$$<A_4(0)A_2(t)> = 0$$

$$<A_5(0)A_2(t)> = 0$$

$$<A_6(0)A_2(t)> = 0$$

$$<A_7(0)A_2(t)> = 0$$

$$<A_8(0)A_2(t)> = 0$$

$$<A_0(0)A_3(t)> = \frac{e^{-b w_1}}{Z} - \frac{e^{-b w_2}}{Z}$$

$$<A_1(0)A_3(t)> = 0$$

$<A_2(0) A_3(t)> \; = \; 0$

$<A_3(0) A_3(t)> \; = \; \frac{e^{-b w_1}}{Z} + \frac{e^{-b w_2}}{Z}$

$<A_4(0) A_3(t)> \; = \; 0$

$<A_5(0) A_3(t)> \; = \; 0$

$<A_6(0) A_3(t)> \; = \; 0$

$<A_7(0) A_3(t)> \; = \; 0$

$<A_8(0) A_3(t)> \; = \; \frac{e^{-b w_1}}{\sqrt{3}\, Z} - \frac{e^{-b w_2}}{\sqrt{3}\, Z}$

$<A_0(0) A_4(t)> \; = \; 0$

$<A_1(0) A_4(t)> \; = \; 0$

$<A_2(0) A_4(t)> \; = \; 0$

$<A_3(0) A_4(t)> \; = \; 0$

$<A_4(0) A_4(t)> \; = \; \frac{e^{-b w_1 + i t w_1 - i t w_3}}{Z} + \frac{e^{-i t w_1 - b w_3 + i t w_3}}{Z}$

$<A_5(0) A_4(t)> \; = \; -\frac{i\, e^{-b w_1 + i t w_1 - i t w_3}}{Z} + \frac{i\, e^{-i t w_1 - b w_3 + i t w_3}}{Z}$

$<A_6(0) A_4(t)> \; = \; 0$

$<A_7(0) A_4(t)> \; = \; 0$

$<A_8(0) A_4(t)> \; = \; 0$

$<A_0(0) A_5(t)> \; = \; 0$

$<A_1(0) A_5(t)> \; = \; 0$

$<A_2(0) A_5(t)> \; = \; 0$

$<A_3(0) A_5(t)> \; = \; 0$

$<A_4(0) A_5(t)> \; = \; \frac{i\, e^{-b w_1 + i t w_1 - i t w_3}}{Z} - \frac{i\, e^{-i t w_1 - b w_3 + i t w_3}}{Z}$

$<A_5(0) A_5(t)> \; = \; \frac{e^{-b w_1 + i t w_1 - i t w_3}}{Z} + \frac{e^{-i t w_1 - b w_3 + i t w_3}}{Z}$

$<A_6(0) A_5(t)> \; = \; 0$

$<A_7(0) A_5(t)> \; = \; 0$

$<A_8(0) A_5(t)> \; = \; 0$

$<A_0(0) A_6(t)> \; = \; 0$

$<A_1(0) A_6(t)> \; = \; 0$

$<A_2(0) A_6(t)> \; = \; 0$

$<A_3(0) A_6(t)> \; = \; 0$

$<A_4(0) A_6(t)> \; = \; 0$

$<A_5(0) A_6(t)> \; = \; 0$

$<A_6(0) A_6(t)> \; = \; \frac{e^{-b w_2 + i t w_2 - i t w_3}}{Z} + \frac{e^{-i t w_2 - b w_3 + i t w_3}}{Z}$

$<A_7(0) A_6(t)> \; = \; -\frac{i\, e^{-b w_2 + i t w_2 - i t w_3}}{Z} + \frac{i\, e^{-i t w_2 - b w_3 + i t w_3}}{Z}$

$<A_8(0)A_6(t)> = 0$

$<A_0(0)A_7(t)> = 0$

$<A_1(0)A_7(t)> = 0$

$<A_2(0)A_7(t)> = 0$

$<A_3(0)A_7(t)> = 0$

$<A_4(0)A_7(t)> = 0$

$<A_5(0)A_7(t)> = 0$

$$<A_6(0)A_7(t)> = \frac{i\, e^{-b w_2 + i t w_2 - i t w_3}}{Z} - \frac{i\, e^{-i t w_2 - b w_3 + i t w_3}}{Z}$$

$$<A_7(0)A_7(t)> = \frac{e^{-b w_2 + i t w_2 - i t w_3}}{Z} + \frac{e^{-i t w_2 - b w_3 + i t w_3}}{Z}$$

$<A_8(0)A_7(t)> = 0$

$$<A_0(0)A_8(t)> = \frac{e^{-b w_1}}{\sqrt{3}\, Z} + \frac{e^{-b w_2}}{\sqrt{3}\, Z} - \frac{2\, e^{-b w_3}}{\sqrt{3}\, Z}$$

$<A_1(0)A_8(t)> = 0$

$<A_2(0)A_8(t)> = 0$

$$<A_3(0)A_8(t)> = \frac{e^{-b w_1}}{\sqrt{3}\, Z} - \frac{e^{-b w_2}}{\sqrt{3}\, Z}$$

$<A_4(0)A_8(t)> = 0$

$<A_5(0)A_8(t)> = 0$

$<A_6(0)A_8(t)> = 0$

$<A_7(0)A_8(t)> = 0$

$$<A_8(0)A_8(t)> = \frac{e^{-b w_1}}{3 Z} + \frac{e^{-b w_2}}{3 Z} + \frac{4\, e^{-b w_3}}{3 Z}$$

3.3.- S=9/2 - Heisenberg

In[∘]:=

```
L110S = {{0, 0, 0, 0, 0, 0, 0, 0, 0, 1}, {0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
   {0, 0, 0, 0, 0, 0, 0, 0, 0, 0}, {0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
   {0, 0, 0, 0, 0, 0, 0, 0, 0, 0}, {0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
   {0, 0, 0, 0, 0, 0, 0, 0, 0, 0}, {0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
   {0, 0, 0, 0, 0, 0, 0, 0, 0, 0}, {1, 0, 0, 0, 0, 0, 0, 0, 0, 0}};
(*Matriz de Gell-Mann generalizada "1,10 simétrica"*)
MatrixForm[L110S]


H10 = {{w1, 0, 0, 0, 0, 0, 0, 0, 0, 0},
   {0, w2, 0, 0, 0, 0, 0, 0, 0, 0}, {0, 0, w3, 0, 0, 0, 0, 0, 0, 0},
   {0, 0, 0, w4, 0, 0, 0, 0, 0, 0}, {0, 0, 0, 0, w5, 0, 0, 0, 0, 0},
   {0, 0, 0, 0, 0, w6, 0, 0, 0, 0}, {0, 0, 0, 0, 0, 0, w7, 0, 0, 0},
   {0, 0, 0, 0, 0, 0, 0, w8, 0, 0}, {0, 0, 0, 0, 0, 0, 0, 0, w9, 0},
   {0, 0, 0, 0, 0, 0, 0, 0, 0, w10}}; (*Hamiltoniano 10x10*)
MatrixForm[H10]

U10 = {{Exp[-I w1 t], 0, 0, 0, 0, 0, 0, 0, 0, 0}, {0, Exp[-I w2 t], 0, 0, 0, 0, 0, 0, 0, 0},
   {0, 0, Exp[-I w3 t], 0, 0, 0, 0, 0, 0, 0}, {0, 0, 0, Exp[-I w4 t], 0, 0, 0, 0, 0, 0},
   {0, 0, 0, 0, Exp[-I w5 t], 0, 0, 0, 0, 0}, {0, 0, 0, 0, 0, Exp[-I w6 t], 0, 0, 0, 0},
   {0, 0, 0, 0, 0, 0, Exp[-I w7 t], 0, 0, 0}, {0, 0, 0, 0, 0, 0, 0, Exp[-I w8 t], 0, 0},
   {0, 0, 0, 0, 0, 0, 0, 0, Exp[-I w9 t], 0}, {0, 0, 0, 0, 0, 0, 0, 0, 0, Exp[-I w10 t]}};
U10dg = {{Exp[I w1 t], 0, 0, 0, 0, 0, 0, 0, 0, 0}, {0, Exp[I w2 t], 0, 0, 0, 0, 0, 0, 0, 0},
   {0, 0, Exp[I w3 t], 0, 0, 0, 0, 0, 0, 0}, {0, 0, 0, Exp[I w4 t], 0, 0, 0, 0, 0, 0},
   {0, 0, 0, 0, Exp[I w5 t], 0, 0, 0, 0, 0}, {0, 0, 0, 0, 0, Exp[I w6 t], 0, 0, 0, 0},
   {0, 0, 0, 0, 0, 0, Exp[I w7 t], 0, 0, 0}, {0, 0, 0, 0, 0, 0, 0, Exp[I w8 t], 0, 0},
   {0, 0, 0, 0, 0, 0, 0, 0, Exp[I w9 t], 0}, {0, 0, 0, 0, 0, 0, 0, 0, 0, Exp[I w10 t]}};
Ro10 = 1/Z {{Exp[-b w1], 0, 0, 0, 0, 0, 0, 0, 0, 0}, {0, Exp[-b w2], 0, 0, 0, 0, 0, 0, 0, 0},
    {0, 0, Exp[-b w3], 0, 0, 0, 0, 0, 0, 0}, {0, 0, 0, Exp[-b w4], 0, 0, 0, 0, 0, 0},
    {0, 0, 0, 0, Exp[-b w5], 0, 0, 0, 0, 0}, {0, 0, 0, 0, 0, Exp[-b w6], 0, 0, 0, 0},
    {0, 0, 0, 0, 0, 0, Exp[-b w7], 0, 0, 0}, {0, 0, 0, 0, 0, 0, 0, Exp[-b w8], 0, 0},
    {0, 0, 0, 0, 0, 0, 0, 0, Exp[-b w9], 0}, {0, 0, 0, 0, 0, 0, 0, 0, 0, Exp[-b w10]}};
```

Out[∘]//MatrixForm=

$$\begin{pmatrix} 0&0&0&0&0&0&0&0&0&1\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&0&0\\ 1&0&0&0&0&0&0&0&0&0 \end{pmatrix}$$

Out[ ]//MatrixForm=

$$\begin{pmatrix} w_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & w_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & w_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & w_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & w_5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & w_6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & w_7 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{10} \end{pmatrix}$$

In[ ]:=
```
Print["<", Subscript[Superscript["A", "S"], "1,10"],
 "(0)", Subscript[Superscript["A", "S"], "1,10"],
 "(t)", "> = ", Tr[Ro10.U10dg.L110S.U10.L110S]]
```

$$<A^S{}_{1,10}(0)\,A^S{}_{1,10}(t)> \;=\; \frac{e^{-b\,w_1+i\,t\,w_1-i\,t\,w_{10}}}{Z}+\frac{e^{-i\,t\,w_1-b\,w_{10}+i\,t\,w_{10}}}{Z}$$

4.1.1.- S=1/2 con pérdidas - Schrödinger

```
Sminus = {{0, 0}, {1, 0}};
L = Sminus;(*operador de Linblad de pérdidas*)
Ldg = ConjugateTranspose[L]; (*Ldagger*)
H2 = {{w1, 0}, {0, w2}}; (*Hamiltoniano 2-dimensional*)
Ro = {{ro11, ro12}, {ro21, ro22}};

(*Calcular el Right Hand Side de la ecuación de
 Lindblad con pérdidas para los cuatro componentes de Ro*)
RHSp11 = Simplify[(-I (H2.Ro - Ro.H2) - (p/2)
      ((Ldg.L.Ro)[[1, 1]] + (Ro.Ldg.L)[[1, 1]] - 2 (L.Ro.Ldg)))[[1, 1]], p ∈ Reals];
RHSp12 = Simplify[(-I (H2.Ro - Ro.H2) - (p/2) ((Ldg.L.Ro)[[1, 2]] +
        (Ro.Ldg.L)[[1, 2]] - 2 (L.Ro.Ldg)))[[1, 2]], p ∈ Reals];
RHSp21 = Simplify[(-I (H2.Ro - Ro.H2) - (p/2) ((Ldg.L.Ro)[[2, 1]] +
        (Ro.Ldg.L)[[2, 1]] - 2 (L.Ro.Ldg)))[[2, 1]], p ∈ Reals];
RHSp22 = Simplify[(-I (H2.Ro - Ro.H2) - (p/2) ((Ldg.L.Ro)[[2, 2]] +
        (Ro.Ldg.L)[[2, 2]] - 2 (L.Ro.Ldg)))[[2, 2]], p ∈ Reals];
```

In[∘]:=
```
(*Left Hand Side = Right Hand Side. Las ecuaciones que
  surgen para cada componente de Ro de la ecuación de Lindblad*)
Print[Subscript["Ro'", 11], "(t)=", RHSp11]
Print[Subscript["Ro'", 12], "(t)=", RHSp12]
Print[Subscript["Ro'", 21], "(t)=", RHSp21]
Print[Subscript["Ro'", 22], "(t)=", RHSp22]
```

$Ro'_{11}(t) = -p\, ro_{11}$

$Ro'_{12}(t) = -\frac{1}{2} ro_{12} (p + 2 i w_1 - 2 i w_2)$

$Ro'_{21}(t) = -\frac{1}{2} ro_{21} (p - 2 i w_1 + 2 i w_2)$

$Ro'_{22}(t) = p\, ro_{11}$

```
(*Resolución de las acuaciones
 diferenciales acopladas obtenidas en el paso anterior*)
```

In[∘]:=
```
DSolve[{ro11'[t] == -p ro11[t], ro12'[t] == -1/2 ro12[t] (p + 2 I w1 - 2 I w2),
   ro21'[t] == -1/2 ro21[t] (p - 2 I w1 + 2 I w2), ro22'[t] == p ro11[t]},
  {ro11[t], ro12[t], ro21[t], ro22[t]}, t]
```

Out[∘]=

$\{\{ro11[t] \to e^{-p t} C[1],\ ro22[t] \to e^{-p t}(-1 + e^{p t}) C[1] + C[2],$
$ro12[t] \to e^{-\frac{p t}{2} - i t w_1 + i t w_2} C[3],\ ro21[t] \to e^{-\frac{p t}{2} + i t w_1 - i t w_2} C[4]\}\}$

4.1.2.- S=1/2 con pérdidas - Heisenberg

```
In[•]:= S0 = {{1, 0}, {0, 1}} ; (*Identidad 2x2*)
Sx = {{0, 1}, {1, 0}} ; (*Sigma x*)
Sy = {{0, -I}, {I, 0}} ; (*Sigma y*)
Sz = {{1, 0}, {0, -1}} ; (*Sigma z*)
Sminus = {{0, 0}, {1, 0}}; (*Sigma minus*)
L = Sminus;(*operador de Linblad de pérdidas*)
Ldg = ConjugateTranspose[L]; (*Ldagger*)
A = {{a11, a12}, {a21, a22}};
H2 = {{w1, 0}, {0, w2}}; (*Hamiltoniano 2-dimensional*)
Ro2 = 1/Z {{Exp[-b w1], 0}, {0, Exp[-b w2]}};
(*Matriz de densidad 2x2, constante en esta imagen*)


(*Calcular el Right Hand Side de la ecuación de Lindblad
 con pérdidas para los cuatro componentes de un A genérico*)
RHSp11 = Simplify[
   (I (H2.A - A.H2) - (p/2) ((Ldg .L .A) [[1, 1]] + (A.Ldg .L) [[1, 1]] - 2 (Ldg. A.L))) [[
    1, 1]] , p ∈ Reals];
RHSp12 = Simplify[(I (H2.A - A.H2) - (p/2)
      ((Ldg .L .A) [[1, 2]] + (A.Ldg .L) [[1, 2]] - 2 (Ldg. A.L))) [[1, 2]] , p ∈ Reals];
RHSp21 = Simplify[(I (H2.A - A.H2) - (p/2) ((Ldg .L .A) [[2, 1]] +
        (A.Ldg .L) [[2, 1]] - 2 (Ldg. A.L))) [[2, 1]] , p ∈ Reals];
RHSp22 = Simplify[(I (H2.A - A.H2) - (p/2) ((Ldg .L .A) [[2, 2]] +
        (A.Ldg .L) [[2, 2]] - 2 (Ldg. A.L))) [[2, 2]] , p ∈ Reals];

(*Left Hand Side = Right Hand Side. Las ecuaciones que
  surgen para cada componente de A de la ecuación de Lindblad*)
Print[Subscript["a'", 11], "(t)=", RHSp11]
Print[Subscript["a'", 12], "(t)=", RHSp12]
Print[Subscript["a'", 21], "(t)=", RHSp21]
Print[Subscript["a'", 22], "(t)=", RHSp22]
```

$a'_{11}(t) = p\,(-a_{11} + a_{22})$

$a'_{12}(t) = -\frac{1}{2}\, a_{12}\, (p - 2\, i\, w_1 + 2\, i\, w_2)$

$a'_{21}(t) = -\frac{1}{2}\, a_{21}\, (p + 2\, i\, w_1 - 2\, i\, w_2)$

$a'_{22}(t) = 0$

```
(*Resolución de las acuaciones diferenciales
 desacopladas obtenidas en el paso anterior*)
DSolve[a11'[t] == p (-a11[t] + a22), a11[t], t]
DSolve[a12'[t] == -1/2 a12[t] (p - 2 I w1 + 2 I w2), a12[t], t]
DSolve[a21'[t] == -1/2 a21[t] (p + 2 I w1 - 2 I w2), a21[t], t]
DSolve[a22'[t] == 0, a22[t], t]
```

Out[∘]= $\{\{a11[t] \to a22 + e^{-p t} C[1]\}\}$

Out[∘]= $\{\{a12[t] \to e^{-\frac{p t}{2} + i t w_1 - i t w_2} C[1]\}\}$

Out[∘]= $\{\{a21[t] \to e^{-\frac{p t}{2} - i t w_1 + i t w_2} C[1]\}\}$

Out[∘]= $\{\{a22[t] \to C[1]\}\}$

In[∘]:=
```
A2p1 = {{1, 0}, {0, 1}} ; (*Evolución de la identidad 2x2 bajo operador de pérdidas,
teniendo en cuenta su forma en t=0*)
```
$A2p2 = \{\{0, e^{-\frac{p t}{2} + I t w_1 - I t w_2}\}, \{e^{-\frac{p t}{2} - I t w_1 + I t w_2}, 0\}\}$; (*Evolución de Sx*)

$A2p3 = \{\{0, -I e^{-\frac{p t}{2} + I t w_1 - I t w_2}\}, \{I e^{-\frac{p t}{2} - I t w_1 + I t w_2}, 0\}\}$; (*Evolución de Sy*)

$A2p4 = \{\{-1 + 2 e^{-p t}, 0\}, \{0, -1\}\}$; (*Evolución de Sz*)

In[∘]:=
```
Print[ Subscript["A", 0], "(t)=" , MatrixForm[A2p1]]
Print[ Subscript["A", 1], "(t)=" , MatrixForm[A2p2]]
Print[ Subscript["A", 2], "(t)=" , MatrixForm[A2p3]]
Print[ Subscript["A", 3], "(t)=" , MatrixForm[A2p4]]
```

$A_0(t) = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$

$A_1(t) = \begin{pmatrix} 0 & e^{-\frac{p t}{2} + i t w_1 - i t w_2} \\ e^{-\frac{p t}{2} - i t w_1 + i t w_2} & 0 \end{pmatrix}$

$A_2(t) = \begin{pmatrix} 0 & -i\, e^{-\frac{p t}{2} + i t w_1 - i t w_2} \\ i\, e^{-\frac{p t}{2} - i t w_1 + i t w_2} & 0 \end{pmatrix}$

$A_3(t) = \begin{pmatrix} -1 + 2 e^{-p t} & 0 \\ 0 & -1 \end{pmatrix}$

```
A0vector = {S0, Sx, Sy, Sz}; (*A_i(0)*)
Aptvector = {A2p1, A2p2, A2p3, A2p4}; (*A_i(t) bajo el operador de pérdidas*)
Do[Do[Print["<", Subscript["A", n], "(0)", Subscript["A", m], "(t)", "> = ",
   Tr[Ro2.Aptvector[[n + 1]].A0vector[[m + 1]]]], {n, 0, 3}], {m, 0, 3}]
(* los índices del vector en mathematica van del 1 al 4,
de ahí el n+1 y el m+1 *)

(*Valores de las autocorrelaciones C_{nm}*)
```

$$\langle A_0(0)A_0(t)\rangle = \frac{e^{-b w_1}}{Z} + \frac{e^{-b w_2}}{Z}$$

$$\langle A_1(0)A_0(t)\rangle = 0$$

$$\langle A_2(0)A_0(t)\rangle = 0$$

$$\langle A_3(0)A_0(t)\rangle = -\frac{e^{-b w_2}}{Z} + \frac{e^{-b w_1}\left(-1+2\,e^{-p t}\right)}{Z}$$

$$\langle A_0(0)A_1(t)\rangle = 0$$

$$\langle A_1(0)A_1(t)\rangle = \frac{e^{-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} + \frac{e^{-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$\langle A_2(0)A_1(t)\rangle = -\frac{i\,e^{-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} + \frac{i\,e^{-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$\langle A_3(0)A_1(t)\rangle = 0$$

$$\langle A_0(0)A_2(t)\rangle = 0$$

$$\langle A_1(0)A_2(t)\rangle = \frac{i\,e^{-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} - \frac{i\,e^{-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$\langle A_2(0)A_2(t)\rangle = \frac{e^{-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} + \frac{e^{-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$\langle A_3(0)A_2(t)\rangle = 0$$

$$\langle A_0(0)A_3(t)\rangle = \frac{e^{-b w_1}}{Z} - \frac{e^{-b w_2}}{Z}$$

$$\langle A_1(0)A_3(t)\rangle = 0$$

$$\langle A_2(0)A_3(t)\rangle = 0$$

$$\langle A_3(0)A_3(t)\rangle = \frac{e^{-b w_2}}{Z} + \frac{e^{-b w_1}\left(-1+2\,e^{-p t}\right)}{Z}$$

```
(*Correlación normalizada A1+a.A3 para w1=3, w2=1, b=1 y p=0.2,
con la proporcion "a" tal que C2p(t)=0 en algún punto*)
```

In[ ]:= $$\text{C2p}[t\_] = \left(\left(\frac{e^{-1}}{e^{-3}+e^{-1}}+\frac{e^{-3}}{e^{-3}+e^{-1}}\right)+\left(\frac{\left(e^{-3}+e^{-1}\right)e^{-\frac{0.2\,\text{Pi}}{4}}}{e^{-1}-e^{-3}+2\,e^{-3}\,e^{-\frac{0.2\,\text{Pi}}{2}}}\right)\left(\frac{e^{-1}}{e^{-3}+e^{-1}}+\frac{e^{-3}\left(-1+2\right)}{e^{-3}+e^{-1}}\right)\right)^{-1}$$
$$\left(\left(\frac{e^{-\frac{0.2\,t}{2}-3\,i\,t-1+i\,t}}{e^{-3}+e^{-1}}+\frac{e^{-\frac{0.2\,t}{2}-3+3\,i\,t-i\,t}}{e^{-3}+e^{-1}}\right)+\left(\frac{\left(e^{-3}+e^{-1}\right)e^{-\frac{0.2\,\text{Pi}}{4}}}{e^{-1}-e^{-3}+2\,e^{-3}\,e^{-\frac{0.2\,\text{Pi}}{2}}}\right)\left(\frac{e^{-1}}{e^{-3}+e^{-1}}+\frac{e^{-3}\left(-1+2\,e^{-0.2\,t}\right)}{e^{-3}+e^{-1}}\right)\right)$$

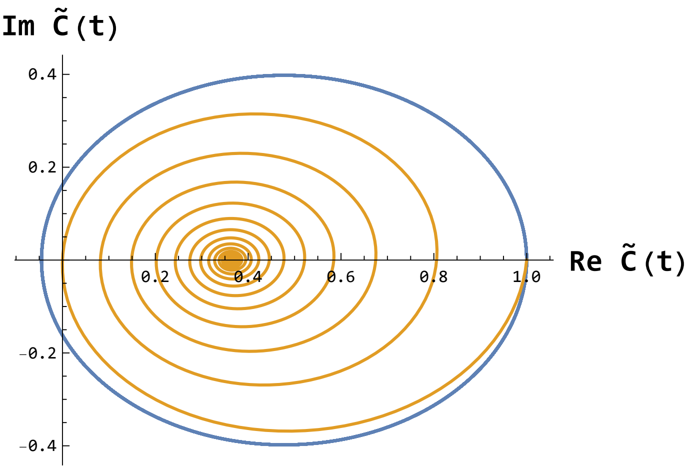
```
(*Correlación A1+a.A3 para w1=3, w2=1, b=1 y p=0,
con la proporción "a" igual al valor que tiene en C2p[t_], cuando p=0.2*)
C2pEstable[t_] =
```

$$\left(\left(\frac{e^{-1}}{e^{-3}+e^{-1}}+\frac{e^{-3}}{e^{-3}+e^{-1}}\right)+\left(\frac{\left(e^{-3}+e^{-1}\right)e^{-\frac{0.2\,\text{Pi}}{4}}}{e^{-1}-e^{-3}+2\,e^{-3}\,e^{-\frac{0.2\,\text{Pi}}{2}}}\right)\left(\frac{e^{-1}}{e^{-3}+e^{-1}}+\frac{e^{-3}\left(-1+2\right)}{e^{-3}+e^{-1}}\right)\right)^{-1}$$
$$\left(\left(\frac{e^{-3\,i\,t-1+i\,t}}{e^{-3}+e^{-1}}+\frac{e^{-3+3\,i\,t-i\,t}}{e^{-3}+e^{-1}}\right)+\left(\frac{\left(e^{-3}+e^{-1}\right)e^{-\frac{0.2\,\text{Pi}}{4}}}{e^{-1}-e^{-3}+2\,e^{-3}\,e^{-\frac{0.2\,\text{Pi}}{2}}}\right)\left(\frac{e^{-1}}{e^{-3}+e^{-1}}+\frac{e^{-3}\left(-1+2\right)}{e^{-3}+e^{-1}}\right)\right)$$

```
(*En amarillo, gráfica con los valores ajustados para que C2p(t) =
 0 en algún punto. En azul la órbita que conseguiríamos si,
manteniendo el resto de valores inalterados, hiciesemos p=0*)
ParametricPlot[{{Re[C2pEstable[t]], Im[C2pEstable[t]]}, {Re[C2p[t]], Im[C2p[t]]}},
 {t, 0, 30 Pi}, AxesLabel → {Style["Re C̃(t)", Bold, 16], Style["Im C̃(t)", Bold, 16]},
 FormatType → StandardForm]
```

Out[ ]= $$0.522646\left(\frac{e^{-1-(0.1+2.\,i)\,t}}{\frac{1}{e^{3}}+\frac{1}{e}}+\frac{e^{-3-(0.1-2.\,i)\,t}}{\frac{1}{e^{3}}+\frac{1}{e}}+0.91334\left(\frac{1}{\left(\frac{1}{e^{3}}+\frac{1}{e}\right)e}+\frac{-1+2\,e^{-0.2\,t}}{\left(\frac{1}{e^{3}}+\frac{1}{e}\right)e^{3}}\right)\right)$$

Out[ ]= $$0.522646\left(0.91334+\frac{e^{-1-2\,i\,t}}{\frac{1}{e^{3}}+\frac{1}{e}}+\frac{e^{-3+2\,i\,t}}{\frac{1}{e^{3}}+\frac{1}{e}}\right)$$

Out[ ]=


4.2.1.- S=1/2 con ganancias - Schrödinger

```
Splus = {{0, 1}, {0, 0}};
L = Splus;(*operador de Linblad de ganancias*)
Ldg = ConjugateTranspose[L]; (*Ldagger*)
H2 = {{w1, 0}, {0, w2}}; (*Hamiltoniano 2-dimensional*)
Ro = {{ro11, ro12}, {ro21, ro22}};

(*Calcular el Right Hand Side de la ecuación de
 Lindblad con ganancias para los cuatro componentes de Ro*)
RHSg11 = Simplify[(-I (H2.Ro - Ro.H2) - (g/2)
     ((Ldg.L.Ro)[[1, 1]] + (Ro.Ldg.L)[[1, 1]] - 2 (L.Ro.Ldg)))[[1, 1]], g ∈ Reals];
RHSg12 = Simplify[(-I (H2.Ro - Ro.H2) - (g/2) ((Ldg.L.Ro)[[1, 2]] +
       (Ro.Ldg.L)[[1, 2]] - 2 (L.Ro.Ldg)))[[1, 2]], g ∈ Reals];
RHSg21 = Simplify[(-I (H2.Ro - Ro.H2) - (g/2) ((Ldg.L.Ro)[[2, 1]] +
       (Ro.Ldg.L)[[2, 1]] - 2 (L.Ro.Ldg)))[[2, 1]], g ∈ Reals];
RHSg22 = Simplify[(-I (H2.Ro - Ro.H2) - (g/2) ((Ldg.L.Ro)[[2, 2]] +
       (Ro.Ldg.L)[[2, 2]] - 2 (L.Ro.Ldg)))[[2, 2]], g ∈ Reals];

(*Left Hand Side = Right Hand Side. Las ecuaciones que
  surgen para cada componente de Ro de la ecuación de Lindblad*)
Print[Subscript["Ro'", 11], "(t)=", RHSg11]
Print[Subscript["Ro'", 12], "(t)=", RHSg12]
Print[Subscript["Ro'", 21], "(t)=", RHSg21]
Print[Subscript["Ro'", 22], "(t)=", RHSg22]
```

$Ro'_{11}(t) = g\, ro_{22}$

como $Ro'_{12}(t) = -\frac{1}{2} ro_{12} (g + 2 i w_1 - 2 i w_2)$

$Ro'_{21}(t) = -\frac{1}{2} ro_{21} (g - 2 i w_1 + 2 i w_2)$

$Ro'_{22}(t) = -g\, ro_{22}$

```
(*Resolución de las acuaciones
 diferenciales acopladas obtenidas en el paso anterior*)
```

In[•]:=
```
DSolve[{ro11'[t] == g ro22[t], ro12'[t] == -1/2 ro12[t] (g + 2 I w1 - 2 I w2),
  ro21'[t] == -1/2 ro21[t] (g - 2 I w1 + 2 I w2), ro22'[t] == -g ro22[t]},
 {ro11[t], ro12[t], ro21[t], ro22[t]}, t]
```

Out[•]=
$\{\{ro11[t] \to C[1] + e^{-g t}(-1 + e^{g t}) C[2],\ ro22[t] \to e^{-g t} C[2],$
$ro12[t] \to e^{-\frac{g t}{2} - i t w_1 + i t w_2} C[3],\ ro21[t] \to e^{-\frac{g t}{2} + i t w_1 - i t w_2} C[4]\}\}$

4.2.2.- S=1/2 con ganancias - Heisenberg

```
In[•]:= S0 = {{1, 0}, {0, 1}} ; (*Identidad 2x2*)
Sx = {{0, 1}, {1, 0}} ; (*Sigma x*)
Sy = {{0, -I}, {I, 0}} ; (*Sigma y*)
Sz = {{1, 0}, {0, -1}} ; (*Sigma z*)
Splus = {{0, 1}, {0, 0}}; (*Sigma minus*)
L = Splus;(*operador de Linblad de ganancias*)
Ldg = ConjugateTranspose[L]; (*Ldagger*)
A = {{a11, a12}, {a21, a22}};
H2 = {{w1, 0}, {0, w2}}; (*Hamiltoniano 2-dimensional*)
Ro2 = 1/Z {{Exp[-b w1], 0}, {0, Exp[-b w2]}};
(*Matriz de densidad 2x2, constante en esta imagen*)


(*Calcular el Right Hand Side de la ecuación de Lindblad
 con ganancias para los cuatro componentes de un A genérico*)
RHSg11 = Simplify[
   (I (H2.A - A.H2) - (g/2) ((Ldg .L .A) [[1, 1]] + (A.Ldg .L) [[1, 1]] - 2 (Ldg. A.L))) [[
    1, 1]] , g ∈ Reals];
RHSg12 = Simplify[(I (H2.A - A.H2) - (g/2)
      ((Ldg .L .A) [[1, 2]] + (A.Ldg .L) [[1, 2]] - 2 (Ldg. A.L))) [[1, 2]] , g ∈ Reals];
RHSg21 = Simplify[(I (H2.A - A.H2) - (g/2) ((Ldg .L .A) [[2, 1]] +
        (A.Ldg .L) [[2, 1]] - 2 (Ldg. A.L))) [[2, 1]] , g ∈ Reals];
RHSg22 = Simplify[(I (H2.A - A.H2) - (g/2) ((Ldg .L .A) [[2, 2]] +
        (A.Ldg .L) [[2, 2]] - 2 (Ldg. A.L))) [[2, 2]] , g ∈ Reals];

(*Left Hand Side = Right Hand Side. Las ecuaciones que
  surgen para cada componente de A de la ecuación de Lindblad*)
Print[Subscript["a'", 11], "(t)=" , RHSg11]
Print[Subscript["a'", 12], "(t)=" , RHSg12]
Print[Subscript["a'", 21], "(t)=" , RHSg21]
Print[Subscript["a'", 22], "(t)=" , RHSg22]
```

$a'_{11}(t) = 0$

$a'_{12}(t) = -\frac{1}{2} a_{12} (g - 2 i w_1 + 2 i w_2)$

$a'_{21}(t) = -\frac{1}{2} a_{21} (g + 2 i w_1 - 2 i w_2)$

$a'_{22}(t) = g (a_{11} - a_{22})$

In[∘]:=
```
(*Resolución de las acuaciones diferenciales
 desacopladas obtenidas en el paso anterior*)
DSolve[a11'[t] == 0, a11[t], t]
DSolve[a12'[t] == -1/2 a12[t] (g - 2 I w1 + 2 I w2), a12[t], t]
DSolve[a21'[t] == -1/2 a21[t] (g + 2 I w1 - 2 I w2), a21[t], t]
DSolve[a22'[t] == p (a11 - a22[t]), a22[t], t]
```

Out[∘]= $\{\{a11[t] \to C[1]\}\}$

Out[∘]= $\{\{a12[t] \to e^{-\frac{g t}{2} + i t w_1 - i t w_2} C[1]\}\}$

Out[∘]= $\{\{a21[t] \to e^{-\frac{g t}{2} - i t w_1 + i t w_2} C[1]\}\}$

Out[∘]= $\{\{a22[t] \to a11 + e^{-p t} C[1]\}\}$

In[∘]:=
```
A2g1 = {{1, 0}, {0, 1}} ; (*Evolución de la identidad 2x2 bajo operador de pérdidas,
teniendo en cuenta su forma en t=0*)
```
$A2g2 = \{\{0, e^{-\frac{g t}{2} + I t w_1 - I t w_2}\}, \{e^{-\frac{g t}{2} - I t w_1 + I t w_2}, 0\}\}$; (*Evolución de Sx*)

$A2g3 = \{\{0, -I e^{-\frac{g t}{2} + I t w_1 - I t w_2}\}, \{I e^{-\frac{g t}{2} - I t w_1 + I t w_2}, 0\}\}$; (*Evolución de Sy*)

$A2g4 = \{\{1, 0\}, \{0, 1 - 2 e^{-g t}\}\}$; (*Evolución de Sz*)

In[∘]:=
```
Print[ Subscript["A", 0], "(t)=" , MatrixForm[A2g1]]
Print[ Subscript["A", 1], "(t)=" , MatrixForm[A2g2]]
Print[ Subscript["A", 2], "(t)=" , MatrixForm[A2g3]]
Print[ Subscript["A", 3], "(t)=" , MatrixForm[A2g4]]
```

$A_0(t) = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$

$A_1(t) = \begin{pmatrix} 0 & e^{-\frac{g t}{2} + i t w_1 - i t w_2} \\ e^{-\frac{g t}{2} - i t w_1 + i t w_2} & 0 \end{pmatrix}$

$A_2(t) = \begin{pmatrix} 0 & -i e^{-\frac{g t}{2} + i t w_1 - i t w_2} \\ i e^{-\frac{g t}{2} - i t w_1 + i t w_2} & 0 \end{pmatrix}$

$A_3(t) = \begin{pmatrix} 1 & 0 \\ 0 & 1 - 2 e^{-g t} \end{pmatrix}$

In[∘]:=
```
A0vector = {S0, Sx, Sy, Sz}; (*A_i(0)*)
Agtvector = {A2g1, A2g2, A2g3, A2g4}; (*A_i(t) bajo el operador de ganancias*)
Do[Do[Print["<", Subscript["A", n], "(0)", Subscript["A", m], "(t)", "> = ",
   Tr[Ro2.Agtvector[[n + 1]].A0vector[[m + 1]]]], {n, 0, 3}], {m, 0, 3}]
(* los índices del vector en mathematica van del 1 al 4,
de ahí el n+1 y el m+1 *)

(*Valores de las autocorrelaciones C_{nm}*)
```

$$<A_0(0)A_0(t)> = \frac{e^{-b w_1}}{Z} + \frac{e^{-b w_2}}{Z}$$

$$<A_1(0)A_0(t)> = 0$$

$$<A_2(0)A_0(t)> = 0$$

$$<A_3(0)A_0(t)> = \frac{e^{-b w_1}}{Z} + \frac{e^{-b w_2}\left(1 - 2 e^{-g t}\right)}{Z}$$

$$<A_0(0)A_1(t)> = 0$$

$$<A_1(0)A_1(t)> = \frac{e^{-\frac{g t}{2} - b w_1 + i t w_1 - i t w_2}}{Z} + \frac{e^{-\frac{g t}{2} - i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_2(0)A_1(t)> = -\frac{i e^{-\frac{g t}{2} - b w_1 + i t w_1 - i t w_2}}{Z} + \frac{i e^{-\frac{g t}{2} - i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_3(0)A_1(t)> = 0$$

$$<A_0(0)A_2(t)> = 0$$

$$<A_1(0)A_2(t)> = \frac{i e^{-\frac{g t}{2} - b w_1 + i t w_1 - i t w_2}}{Z} - \frac{i e^{-\frac{g t}{2} - i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_2(0)A_2(t)> = \frac{e^{-\frac{g t}{2} - b w_1 + i t w_1 - i t w_2}}{Z} + \frac{e^{-\frac{g t}{2} - i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_3(0)A_2(t)> = 0$$

$$<A_0(0)A_3(t)> = \frac{e^{-b w_1}}{Z} - \frac{e^{-b w_2}}{Z}$$

$$<A_1(0)A_3(t)> = 0$$

$$<A_2(0)A_3(t)> = 0$$

$$<A_3(0)A_3(t)> = \frac{e^{-b w_1}}{Z} - \frac{e^{-b w_2}\left(1 - 2 e^{-g t}\right)}{Z}$$

```
(*Correlación normalizada A1+a.A3 para w1=3, w2=1, b=1 y g=0.2,
con la proporcion "a" tal que C2g(t)=0 en algún punto*)
```

In[ ]:=

$$C2g[t\_] = \left(\left(\frac{e^{-1}}{e^{-3}+e^{-1}}+\frac{e^{-3}}{e^{-3}+e^{-1}}\right)+\left(\frac{(e^{-3}+e^{-1})\,e^{-\frac{0.2\,Pi}{4}}}{e^{-3}-e^{-1}+2\,e^{-1}\,e^{-\frac{0.2\,Pi}{2}}}\right)\left(\frac{e^{-3}}{e^{-3}+e^{-1}}-\frac{e^{-1}\,(1-2)}{e^{-3}+e^{-1}}\right)\right)^{-1}$$

$$\left(\left(\frac{e^{-\frac{0.2t}{2}-3\,i\,t-1+i\,t}}{e^{-3}+e^{-1}}+\frac{e^{-\frac{0.2t}{2}-3+3\,i\,t-i\,t}}{e^{-3}+e^{-1}}\right)+\left(\frac{(e^{-3}+e^{-1})\,e^{-\frac{0.2\,Pi}{4}}}{e^{-3}-e^{-1}+2\,e^{-1}\,e^{-\frac{0.2\,Pi}{2}}}\right)\left(\frac{e^{-3}}{e^{-3}+e^{-1}}-\frac{e^{-1}\,(1-2\,e^{-0.2\,t})}{e^{-3}+e^{-1}}\right)\right)$$

(*Correlación A1+a.A3 para w1=3, w2=1, b=1 y g=0,
con la proporción "a" igual al valor que tiene en C2g[t_], cuando g=0.2*)

$$C2gEstable[t\_] = \left(\left(\frac{e^{-1}}{e^{-3}+e^{-1}}+\frac{e^{-3}}{e^{-3}+e^{-1}}\right)+\left(\frac{(e^{-3}+e^{-1})\,e^{-\frac{0.2\,Pi}{4}}}{e^{-3}-e^{-1}+2\,e^{-1}\,e^{-\frac{0.2\,Pi}{2}}}\right)\left(\frac{e^{-3}}{e^{-3}+e^{-1}}-\frac{e^{-1}\,(1-2)}{e^{-3}+e^{-1}}\right)\right)^{-1}$$

$$\left(\left(\frac{e^{-3\,i\,t-1+i\,t}}{e^{-3}+e^{-1}}+\frac{e^{-3+3\,i\,t-i\,t}}{e^{-3}+e^{-1}}\right)+\left(\frac{(e^{-3}+e^{-1})\,e^{-\frac{0.2\,Pi}{4}}}{e^{-3}-e^{-1}+2\,e^{-1}\,e^{-\frac{0.2\,Pi}{2}}}\right)\left(\frac{e^{-3}}{e^{-3}+e^{-1}}-\frac{e^{-1}\,(1-2)}{e^{-3}+e^{-1}}\right)\right)$$

```
(*En amarillo, gráfica con los valores ajustados para que C2g(t) =
 0 en algún punto. En azul la órbita que conseguiríamos si,
manteniendo el resto de valores inalterados, hiciesemos g=0*)
ParametricPlot[{{Re[C2gEstable[t]], Im[C2gEstable[t]]}, {Re[C2g[t]], Im[C2g[t]]}},
 {t, 0, 30 Pi}, AxesLabel → {Style["Re C̃(t)" , Bold, 16], Style["Im C̃(t)", Bold, 16]},
 FormatType → StandardForm]
```

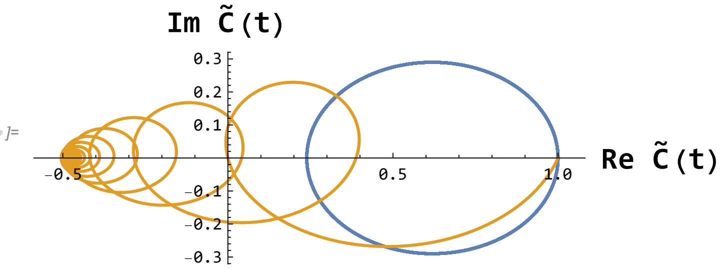
Out[ ]=

$$0.380571\left(\frac{e^{-1-(0.1+2.\,i)\,t}}{\frac{1}{e^3}+\frac{1}{e}}+\frac{e^{-3-(0.1-2.\,i)\,t}}{\frac{1}{e^3}+\frac{1}{e}}+1.62763\left(\frac{1}{\left(\frac{1}{e^3}+\frac{1}{e}\right)e^3}-\frac{1-2\,e^{-0.2\,t}}{\left(\frac{1}{e^3}+\frac{1}{e}\right)e}\right)\right)$$

Out[ ]=

$$0.380571\left(1.62763+\frac{e^{-1-2\,i\,t}}{\frac{1}{e^3}+\frac{1}{e}}+\frac{e^{-3+2\,i\,t}}{\frac{1}{e^3}+\frac{1}{e}}\right)$$

Out[ ]=



4.3.1.- S=1/2 con pérdidas y ganancias - Schrödinger

In[∘]:=
```
Sminus = {{0, 0}, {1, 0}};(*operador de Linblad de pérdidas. SplusDagger*)
Splus = {{0, 1}, {0, 0}};(*operador de Linblad de ganancias. SminusDagger*)
H2 = {{w1, 0}, {0, w2}}; (*Hamiltoniano 2-dimensional*)
Ro = {{ro11, ro12}, {ro21, ro22}};

(*Calcular el Right Hand Side de la ecuación de Lindblad
 con pérdidas y ganancias para los cuatro componentes de Ro*)
RHSpg11 = Simplify[(-I (H2.Ro - Ro.H2) -
      (p/2) ((Splus.Sminus.Ro) + (Ro.Splus.Sminus) - 2 (Sminus.Ro.Splus)) -
      (g/2) ((Sminus.Splus.Ro) + (Ro.Sminus.Splus) - 2 (Splus. Ro.Sminus)))[[
    1, 1]] , {p ∈ Reals, g ∈ Reals}];
RHSpg12 = Simplify[(-I (H2.Ro - Ro.H2) -
      (p/2) ((Splus.Sminus.Ro) + (Ro.Splus.Sminus) - 2 (Sminus.Ro.Splus)) -
      (g/2) ((Sminus.Splus.Ro) + (Ro.Sminus.Splus) - 2 (Splus. Ro.Sminus)))[[
    1, 2]] , {p ∈ Reals, g ∈ Reals}];
RHSpg21 = Simplify[(-I (H2.Ro - Ro.H2) -
      (p/2) ((Splus.Sminus.Ro) + (Ro.Splus.Sminus) - 2 (Sminus.Ro.Splus)) -
      (g/2) ((Sminus.Splus.Ro) + (Ro.Sminus.Splus) - 2 (Splus. Ro.Sminus)))[[
    2, 1]] , {p ∈ Reals, g ∈ Reals}];
RHSpg22 = Simplify[(-I (H2.Ro - Ro.H2) -
      (p/2) ((Splus.Sminus.Ro) + (Ro.Splus.Sminus) - 2 (Sminus.Ro.Splus)) -
      (g/2) ((Sminus.Splus.Ro) + (Ro.Sminus.Splus) - 2 (Splus. Ro.Sminus)))[[
    2, 2]] , {p ∈ Reals, g ∈ Reals}];
```

In[∘]:=
```
(*Left Hand Side = Right Hand Side. Las ecuaciones que
  surgen para cada componente de Ro de la ecuación de Lindblad*)
Print[Subscript["Ro'", 11], "(t)=", RHSpg11]
Print[Subscript["Ro'", 12], "(t)=", RHSpg12]
Print[Subscript["Ro'", 21], "(t)=", RHSpg21]
Print[Subscript["Ro'", 22], "(t)=", RHSpg22]
```

$Ro'_{11}(t) = -p\, ro_{11} + g\, ro_{22}$

$Ro'_{12}(t) = -\frac{1}{2} ro_{12} (g + p + 2 i w_1 - 2 i w_2)$

$Ro'_{21}(t) = -\frac{1}{2} ro_{21} (g + p - 2 i w_1 + 2 i w_2)$

$Ro'_{22}(t) = p\, ro_{11} - g\, ro_{22}$

```
(*Resolución de las acuaciones
 diferenciales acopladas obtenidas en el paso anterior*)
```

In[∘]:=
```
DSolve[{ro11'[t] == -p ro11[t] + g ro22[t], ro12'[t] == -1/2 ro12[t] (p + g + 2 I w1 - 2 I w2),
  ro21'[t] == -1/2 ro21[t] (p + g - 2 I w1 + 2 I w2), ro22'[t] == p ro11[t] - g ro22[t]},
 {ro11[t], ro12[t], ro21[t], ro22[t]} , t]
```

Out[∘]=

$$\left\{\left\{ro11[t] \to \frac{\left(g + e^{(-g-p)\,t}\,p\right)\,C[1]}{g+p} - \frac{\left(-1 + e^{(-g-p)\,t}\right)\,g\,C[2]}{g+p},\right.\right.$$

$$ro22[t] \to -\frac{\left(-1 + e^{(-g-p)\,t}\right)\,p\,C[1]}{g+p} + \frac{\left(e^{(-g-p)\,t}\,g + p\right)\,C[2]}{g+p},$$

$$\left.\left. ro12[t] \to e^{-\frac{g\,t}{2}-\frac{p\,t}{2}-i\,t\,w_1+i\,t\,w_2}\,C[3],\ ro21[t] \to e^{-\frac{g\,t}{2}-\frac{p\,t}{2}+i\,t\,w_1-i\,t\,w_2}\,C[4]\right\}\right\}$$

4.3.2.- S=1/2 con pérdidas y ganancias- Heisenberg

In[ ]:=
```
S0 = {{1, 0}, {0, 1}} ; (*Identidad 2x2*)
Sx = {{0, 1}, {1, 0}} ; (*Sigma x*)
Sy = {{0, -I}, {I, 0}} ; (*Sigma y*)
Sz = {{1, 0}, {0, -1}} ; (*Sigma z*)
Sminus = {{0, 0}, {1, 0}}; (*operador de Linblad de pérdidas. SplusDagger*)
Splus = {{0, 1}, {0, 0}};(*operador de Linblad de ganancias. SminusDagger*)
A = {{a11, a12}, {a21, a22}};
H2 = {{w1, 0}, {0, w2}}; (*Hamiltoniano 2-dimensional*)
Ro2 = 1/Z {{Exp[-b w1], 0}, {0, Exp[-b w2]}};
(*Matriz de densidad 2x2, constante en esta imagen*)


(*Calcular el Right Hand Side de la ecuación de Lindblad con
 pérdidas y ganancias para los cuatro componentes de un A genérico*)
RHSpg11 = Simplify[(I (H2.A - A.H2) - (p/2)
      ((Splus .Sminus .A) [[1, 1]] + (A.Splus .Sminus) [[1, 1]] - 2 (Splus. A.Sminus))) [[
    1, 1]] - (g/2) ((Sminus .Splus .A) [[1, 1]] + (A.Sminus .Splus) [[1, 1]] -
      2 (Sminus. A.Splus)) [[1, 1]] , {p ∈ Reals, g ∈ Reals}];
RHSpg12 = Simplify[(I (H2.A - A.H2) - (p/2) ((Splus .Sminus .A) [[1, 2]] +
        (A.Splus .Sminus) [[1, 2]] - 2 (Splus. A.Sminus))) [[1, 2]] - (g/2)
    ((Sminus .Splus .A) [[1, 2]] + (A.Sminus .Splus) [[1, 2]] - 2 (Sminus. A.Splus)) [[
     1, 2]] , {p ∈ Reals, g ∈ Reals}];
RHSpg21 = Simplify[(I (H2.A - A.H2) - (p/2) ((Splus .Sminus .A) [[2, 1]] +
        (A.Splus .Sminus) [[2, 1]] - 2 (Splus. A.Sminus))) [[2, 1]] - (g/2)
    ((Sminus .Splus .A) [[2, 1]] + (A.Sminus .Splus) [[2, 1]] - 2 (Sminus. A.Splus)) [[
     2, 1]] , {p ∈ Reals, g ∈ Reals}];
RHSpg22 = Simplify[(I (H2.A - A.H2) - (p/2) ((Splus .Sminus .A) [[2, 2]] +
        (A.Splus .Sminus) [[2, 2]] - 2 (Splus. A.Sminus))) [[2, 2]] - (g/2)
    ((Sminus .Splus .A) [[2, 2]] + (A.Sminus .Splus) [[2, 2]] - 2 (Sminus. A.Splus)) [[
     2, 2]] , {p ∈ Reals, g ∈ Reals}];

(*Left Hand Side = Right Hand Side. Las ecuaciones que
  surgen para cada componente de A de la ecuación de Lindblad*)
Print[Subscript["a'", 11], "(t)=" , RHSpg11]
Print[Subscript["a'", 12], "(t)=" , RHSpg12]
Print[Subscript["a'", 21], "(t)=" , RHSpg21]
Print[Subscript["a'", 22], "(t)=" , RHSpg22]
```

$a'_{11}(t) = p\,(-a_{11} + a_{22})$

$a'_{12}(t) = -\frac{1}{2}\, a_{12}\,(g + p - 2\,i\,w_1 + 2\,i\,w_2)$

$a'_{21}(t) = -\frac{1}{2}\, a_{21}\,(g + p + 2\,i\,w_1 - 2\,i\,w_2)$

$a'_{22}(t) = g\,(a_{11} - a_{22})$

In[∘]:=
```
(*Resolución de las acuaciones diferenciales
 acopladas obtenidas en el paso anterior*)
DSolve[{a11'[t] == p (-a11[t] + a22[t]),
  a12'[t] == -1/2 a12[t] (g + p - 2 I w1 + 2 I w2),
  a21'[t] ==-1/2 a21[t] (g + p + 2 I w1 - 2 I w2),
  a22'[t] == g (a11[t] - a22[t])},
 {a11[t], a12[t], a21[t], a22[t]} , t]
```

Out[∘]=

$$\left\{\left\{a11[t] \to \frac{\left(g + e^{(-g-p)\,t}\,p\right) C[1]}{g+p} - \frac{\left(-1 + e^{(-g-p)\,t}\right) p\, C[2]}{g+p},\right.\right.$$
$$a22[t] \to -\frac{\left(-1 + e^{(-g-p)\,t}\right) g\, C[1]}{g+p} + \frac{\left(e^{(-g-p)\,t}\,g + p\right) C[2]}{g+p},$$
$$\left.\left. a12[t] \to e^{-\frac{g t}{2}-\frac{p t}{2}+i t w_1 - i t w_2}\, C[3],\ a21[t] \to e^{-\frac{g t}{2}-\frac{p t}{2}-i t w_1 + i t w_2}\, C[4]\right\}\right\}$$

In[∘]:=
```
A2pg1 = {{1, 0}, {0, 1}} ;
(*Evolución de la identidad 2x2 bajo operadores de pérdidas y ganancias,
teniendo en cuenta su forma en t=0*)
```

$$A2pg2 = \left\{\left\{0,\ e^{-\frac{g t}{2}-\frac{p t}{2}+I t w_1 - I t w_2}\right\},\ \left\{e^{-\frac{g t}{2}-\frac{p t}{2}-I t w_1 + I t w_2},\ 0\right\}\right\};\ \text{(*Evolución de Sx*)}$$

$$A2pg3 = \left\{\left\{0,\ -I\, e^{-\frac{g t}{2}-\frac{p t}{2}+I t w_1 - I t w_2}\right\},\ \left\{I\, e^{-\frac{g t}{2}-\frac{p t}{2}-I t w_1 + I t w_2},\ 0\right\}\right\};\ \text{(*Evolución de Sy*)}$$

$$A2pg4 = \left\{\left\{\frac{g - p + 2\, e^{(-g-p)\,t}\, p}{g+p},\ 0\right\},\ \left\{0,\ \frac{g - p\ - 2\, e^{(-g-p)\,t}\, g}{g+p}\right\}\right\};\ \text{(*Evolución de Sz*)}$$

In[∘]:=
```
Print[ Subscript["A", 0], "(t)=" , MatrixForm[A2pg1]]
Print[ Subscript["A", 1], "(t)=" , MatrixForm[A2pg2]]
Print[ Subscript["A", 2], "(t)=" , MatrixForm[A2pg3]]
Print[ Subscript["A", 3], "(t)=" , MatrixForm[A2pg4]]
```

$$A_0(t) = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$A_1(t) = \begin{pmatrix} 0 & e^{-\frac{g t}{2}-\frac{p t}{2}+i t w_1 - i t w_2} \\ e^{-\frac{g t}{2}-\frac{p t}{2}-i t w_1 + i t w_2} & 0 \end{pmatrix}$$

$$A_2(t) = \begin{pmatrix} 0 & -i\, e^{-\frac{g t}{2}-\frac{p t}{2}+i t w_1 - i t w_2} \\ i\, e^{-\frac{g t}{2}-\frac{p t}{2}-i t w_1 + i t w_2} & 0 \end{pmatrix}$$

$$A_3(t) = \begin{pmatrix} \frac{g-p+2\, e^{(-g-p)\,t}\, p}{g+p} & 0 \\ 0 & \frac{g-2\, e^{(-g-p)\,t}\, g-p}{g+p} \end{pmatrix}$$

In[∘]:=
```
A0vector = {S0, Sx, Sy, Sz}; (*A_i(0)*)
Apgtvector = {A2pg1, A2pg2, A2pg3, A2pg4}; (*A_i(t) bajo el operador de pérdidas*)
Do[Do[Print["<", Subscript["A", n], "(0)", Subscript["A", m], "(t)", "> = ",
   Tr[Ro2.Apgtvector[[n + 1]].A0vector[[m + 1]]]], {n, 0, 3}], {m, 0, 3}]
(* los índices del vector en mathematica van del 1 al 4,
de ahí el n+1 y el m+1 *)

(*Valores de las autocorrelaciones C_{nm}*)
```

$$<A_0(0)A_0(t)> = \frac{e^{-b w_1}}{Z} + \frac{e^{-b w_2}}{Z}$$

$$<A_1(0)A_0(t)> = 0$$

$$<A_2(0)A_0(t)> = 0$$

$$<A_3(0)A_0(t)> = \frac{e^{-b w_2}\left(g - 2 e^{(-g-p) t} g - p\right)}{(g+p) Z} + \frac{e^{-b w_1}\left(g - p + 2 e^{(-g-p) t} p\right)}{(g+p) Z}$$

$$<A_0(0)A_1(t)> = 0$$

$$<A_1(0)A_1(t)> = \frac{e^{-\frac{g t}{2}-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} + \frac{e^{-\frac{g t}{2}-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$<A_2(0)A_1(t)> = -\frac{i e^{-\frac{g t}{2}-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} + \frac{i e^{-\frac{g t}{2}-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$<A_3(0)A_1(t)> = 0$$

$$<A_0(0)A_2(t)> = 0$$

$$<A_1(0)A_2(t)> = \frac{i e^{-\frac{g t}{2}-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} - \frac{i e^{-\frac{g t}{2}-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$<A_2(0)A_2(t)> = \frac{e^{-\frac{g t}{2}-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} + \frac{e^{-\frac{g t}{2}-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$<A_3(0)A_2(t)> = 0$$

$$<A_0(0)A_3(t)> = \frac{e^{-b w_1}}{Z} - \frac{e^{-b w_2}}{Z}$$

$$<A_1(0)A_3(t)> = 0$$

$$<A_2(0)A_3(t)> = 0$$

$$<A_3(0)A_3(t)> = -\frac{e^{-b w_2}\left(g - 2 e^{(-g-p) t} g - p\right)}{(g+p) Z} + \frac{e^{-b w_1}\left(g - p + 2 e^{(-g-p) t} p\right)}{(g+p) Z}$$

```
(*Correlación normalizada A1+a.A3 para w1=3, w2=1, b=1,
p=0.2  g=0.2, con la proporcion "a" tal que C2pg(t)=0 en algún punto*)
```

In[ ]:= C2pg[t_] =

$$\left(\left(\frac{e^{-1}}{e^{-3}+e^{-1}}+\frac{e^{-3}}{e^{-3}+e^{-1}}\right)+\left(\left(e^{-\frac{0.2\,Pi}{2\times 2}-\frac{0.2\,Pi}{2\times 2}-1}+e^{-\frac{0.2\,Pi}{2\times 2}-\frac{0.2\,Pi}{2\times 2}-3}\right)\Big/\left(\frac{1}{(0.2+0.2)}\left(e^{-1}\left(0.2-2\,e^{(-0.2-0.2)\frac{Pi}{2}}\,0.2-0.2\right)+e^{-3}\left(0.2-0.2+2\,e^{(-0.2-0.2)\frac{Pi}{2}}\,0.2\right)\right)\right)\right)\left(\frac{e^{-1}\left(0.2-2\times 0.2-0.2\right)}{(0.2+0.2)\left(e^{-3}+e^{-1}\right)}+\frac{e^{-3}\left(0.2-0.2+2\times 0.2\right)}{(0.2+0.2)\left(e^{-3}+e^{-1}\right)}\right)\right)^{-1}$$

$$\left(\left(\frac{e^{-\frac{0.2\,t}{2}-\frac{0.2\,t}{2}-3\,i\,t-1+i\,t}}{e^{-3}+e^{-1}}+\frac{e^{-\frac{0.2\,t}{2}-\frac{0.2\,t}{2}-3+3\,i\,t-i\,t}}{e^{-3}+e^{-1}}\right)+\left(\left(e^{-\frac{0.2\,Pi}{2\times 2}-\frac{0.2\,Pi}{2\times 2}-1}+e^{-\frac{0.2\,Pi}{2\times 2}-\frac{0.2\,Pi}{2\times 2}-3}\right)\Big/\left(\frac{1}{(0.2+0.2)}\left(e^{-1}\left(0.2-2\,e^{(-0.2-0.2)\frac{Pi}{2}}\,0.2-0.2\right)+e^{-3}\left(0.2-0.2+2\,e^{(-0.2-0.2)\frac{Pi}{2}}\,0.2\right)\right)\right)\right)\left(\frac{e^{-1}\left(0.2-2\,e^{(-0.2-0.2)\,t}\,0.2-0.2\right)}{(0.2+0.2)\left(e^{-3}+e^{-1}\right)}+\frac{e^{-3}\left(0.2-0.2+2\,e^{(-0.2-0.2)\,t}\,0.2\right)}{(0.2+0.2)\left(e^{-3}+e^{-1}\right)}\right)\right)$$

(*Correlación A1+a.A3 para w1=3, w2=1, b=1, p=0, g=0,
con la proporción "a" igual al valor que tiene en C2pg[t_], cuando p=0.2 y g=0.2*)

C2pgEstable[t_] =

$$\left(\left(\frac{e^{-3}}{\left(e^{-3}+e^{-1}\right)}+\frac{e^{-1}}{\left(e^{-3}+e^{-1}\right)}\right)+(0.2+0.2)\,e^{\frac{-(0.2+0.2)\frac{Pi}{2}}{2}}\left(e^{-3}+e^{-1}\right)\left(-e^{-1}\left(0.2-0.2-2\times 0.2\,e^{-(0.2+0.2)\frac{Pi}{2}}\right)+e^{-3}\left(0.2-0.2+2\times 0.2\,e^{-(0.2+0.2)\frac{Pi}{2}}\right)\right)^{-1}\right)^{-1}$$

$$\left(\left(\frac{e^{3\,i\,t-3-i\,t}}{\left(e^{-3}+e^{-1}\right)}+\frac{e^{i\,t-1-3\,i\,t}}{\left(e^{-3}+e^{-1}\right)}\right)+(0.2+0.2)\,e^{\frac{-(0.2+0.2)\frac{Pi}{2}}{2}}\left(e^{-3}+e^{-1}\right)\left(-e^{-1}\left(0.2-0.2-2\times 0.2\,e^{-(0.2+0.2)\frac{Pi}{2}}\right)+e^{-3}\left(0.2-0.2+2\times 0.2\,e^{-(0.2+0.2)\frac{Pi}{2}}\right)\right)^{-1}\right)$$

(*En amarillo, gráfica con los valores ajustados para que C2p(t) =
0 en algún punto. En azul la órbita que conseguiríamos si,
manteniendo el resto de valores inalterados, hiciesemos p=0*)

```
ParametricPlot[
 {{Re[C2pgEstable[t]], Im[C2pgEstable[t]]}, {Re[C2pg[t]], Im[C2pg[t]]}},
 {t, 0, 30 Pi}, AxesLabel → {Style["Re C̃(t)" , Bold, 16], Style["Im C̃(t)", Bold, 16]},
 FormatType → StandardForm]
```

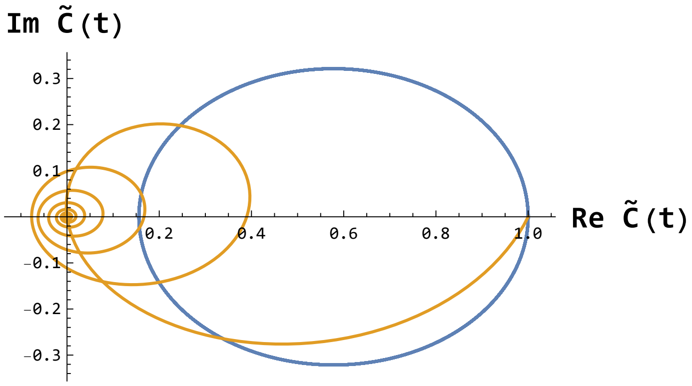
Out[ ]=

$$0.4221\left(\frac{e^{-1-(0.2+2.\,i)\,t}}{\frac{1}{e^{3}}+\frac{1}{e}}+\frac{e^{-3-(0.2-2.\,i)\,t}}{\frac{1}{e^{3}}+\frac{1}{e}}-1.79769\left(2.20199\left(0.-0.4\,e^{-0.4\,t}\right)+0.298007\left(0.+0.4\,e^{-0.4\,t}\right)\right)\right)$$

Out[ ]=

$$0.4221\left(1.36911+\frac{e^{-1-2\,i\,t}}{\frac{1}{e^{3}}+\frac{1}{e}}+\frac{e^{-3+2\,i\,t}}{\frac{1}{e^{3}}+\frac{1}{e}}\right)$$

Out[ ]=



4.4.1.- S=1/2 con defasaje - Schrödinger

```
Sz = {{1, 0}, {0, -1}};
L = Sz;(*operador de Linblad de defasaje*)
Ldg = ConjugateTranspose[L]; (*Ldagger*)
H2 = {{w1, 0}, {0, w2}}; (*Hamiltoniano 2-dimensional*)
Ro = {{ro11, ro12}, {ro21, ro22}};

(*Calcular el Right Hand Side de la ecuación de
 Lindblad con defasaje para los cuatro componentes de Ro*)
RHSd11 = Simplify[(-I (H2.Ro - Ro.H2) - (d/2)
     ((Ldg.L.Ro)[[1, 1]] + (Ro.Ldg.L)[[1, 1]] - 2 (L.Ro.Ldg)))[[1, 1]], d ∈ Reals];
RHSd12 = Simplify[(-I (H2.Ro - Ro.H2) - (d/2) ((Ldg.L.Ro)[[1, 2]] +
       (Ro.Ldg.L)[[1, 2]] - 2 (L.Ro.Ldg)))[[1, 2]], d ∈ Reals];
RHSd21 = Simplify[(-I (H2.Ro - Ro.H2) - (d/2) ((Ldg.L.Ro)[[2, 1]] +
       (Ro.Ldg.L)[[2, 1]] - 2 (L.Ro.Ldg)))[[2, 1]], d ∈ Reals];
RHSd22 = Simplify[(-I (H2.Ro - Ro.H2) - (d/2) ((Ldg.L.Ro)[[2, 2]] +
       (Ro.Ldg.L)[[2, 2]] - 2 (L.Ro.Ldg)))[[2, 2]], d ∈ Reals];
```

In[∘]:=
```
(*Left Hand Side = Right Hand Side. Las ecuaciones que
   surgen para cada componente de Ro de la ecuación de Lindblad*)
Print[Subscript["Ro'", 11], "(t)=", RHSd11]
Print[Subscript["Ro'", 12], "(t)=", RHSd12]
Print[Subscript["Ro'", 21], "(t)=", RHSd21]
Print[Subscript["Ro'", 22], "(t)=", RHSd22]
```

$Ro'_{11}(t)=0$

$Ro'_{12}(t)=ro_{12}\ (-2\,d - i\,w_1 + i\,w_2)$

$Ro'_{21}(t)=ro_{21}\ (-2\,d + i\,w_1 - i\,w_2)$

$Ro'_{22}(t)=0$

```
(*Resolución de las acuaciones
 diferenciales acopladas obtenidas en el paso anterior*)
```

In[∘]:=
```
DSolve[{ro11'[t] == 0, ro12'[t] == ro12[t] (-2 d - I w1 + I w2),
   ro21'[t] == ro21[t] (2 d + I w1 - I w2), ro22'[t] == 0},
  {ro11[t], ro12[t], ro21[t], ro22[t]}, t]
```

Out[∘]= $\{\{ro11[t] \to C[1],\ ro12[t] \to e^{-2\,d\,t - i\,t\,w_1 + i\,t\,w_2}\,C[2],\ ro21[t] \to e^{2\,d\,t + i\,t\,w_1 - i\,t\,w_2}\,C[3],\ ro22[t] \to C[4]\}\}$

4.4.2- S=1/2 con defasaje - Heisenberg

```
S0 = {{1, 0}, {0, 1}} ; (*Identidad 2x2*)
Sx = {{0, 1}, {1, 0}} ; (*Sigma x*)
Sy = {{0, -I}, {I, 0}} ; (*Sigma y*)
Sz = {{1, 0}, {0, -1}} ; (*Sigma z*)
L = Sz;(*operador de Linblad de defasaje*)
Ldg = ConjugateTranspose[L]; (*Ldagger*)
A = {{a11, a12}, {a21, a22}};
H2 = {{w1, 0}, {0, w2}}; (*Hamiltoniano 2-dimensional*)
Ro2 = 1/Z {{Exp[-b w1], 0}, {0, Exp[-b w2]}};
(*Matriz de densidad 2x2, constante en esta imagen*)


(*Calcular el Right Hand Side de la ecuación de Lindblad
 con defasaje para los cuatro componentes de un A genérico*)
RHSd11 = Simplify[
    (I (H2.A - A.H2) - (d/2) ((Ldg .L .A) [[1, 1]] + (A.Ldg .L) [[1, 1]] - 2 (Ldg. A.L))) [[
     1, 1]] , d ∈ Reals];
RHSd12 = Simplify[(I (H2.A - A.H2) - (d/2)
         ((Ldg .L .A) [[1, 2]] + (A.Ldg .L) [[1, 2]] - 2 (Ldg. A.L))) [[1, 2]] , d ∈ Reals];
RHSd21 = Simplify[(I (H2.A - A.H2) - (d/2) ((Ldg .L .A) [[2, 1]] +
          (A.Ldg .L) [[2, 1]] - 2 (Ldg. A.L))) [[2, 1]] , d ∈ Reals];
RHSd22 = Simplify[(I (H2.A - A.H2) - (d/2) ((Ldg .L .A) [[2, 2]] +
          (A.Ldg .L) [[2, 2]] - 2 (Ldg. A.L))) [[2, 2]] , d ∈ Reals];

(*Left Hand Side = Right Hand Side. Las ecuaciones que
  surgen para cada componente de A de la ecuación de Lindblad*)
Print[Subscript["a'", 11], "(t)=", RHSd11]
Print[Subscript["a'", 12], "(t)=", RHSd12]
Print[Subscript["a'", 21], "(t)=", RHSd21]
Print[Subscript["a'", 22], "(t)=", RHSd22]
```

$a'_{11}(t) = 0$

$a'_{12}(t) = -a_{12}\,(2\,d - i\,w_1 + i\,w_2)$

$a'_{21}(t) = -a_{21}\,(2\,d + i\,w_1 - i\,w_2)$

$a'_{22}(t) = 0$

In[∘]:=
```
(*Resolución de las acuaciones diferenciales
 desacopladas obtenidas en el paso anterior*)
DSolve[a11'[t] == 0, a11[t], t]
DSolve[a12'[t] == -a12[t] (2 d - I w1 + I w2), a12[t], t]
DSolve[a21'[t] == -a21[t] (2 d + I w1 - I w2), a21[t], t]
DSolve[a22'[t] == 0, a22[t], t]
```

Out[∘]= $\{\{a11[t] \to C[1]\}\}$

Out[∘]= $\{\{a12[t] \to e^{-2 d t + i t w_1 - i t w_2} C[1]\}\}$

Out[∘]= $\{\{a21[t] \to e^{-2 d t - i t w_1 + i t w_2} C[1]\}\}$

Out[∘]= $\{\{a22[t] \to C[1]\}\}$

In[∘]:=
```
A2d1 = {{1, 0}, {0, 1}} ; (*Evolución de la identidad 2x2 bajo operador de pérdidas,
teniendo en cuenta su forma en t=0*)
A2d2 = {{0, e^(-2 d t+I t w1-I t w2)}, {e^(-2 d t-I t w1+I t w2), 0}} ; (*Evolución de Sx*)
A2d3 = {{0, -I e^(-2 d t+I t w1-I t w2)}, {I e^(-2 d t-I t w1+I t w2), 0}} ; (*Evolución de Sy*)
A2d4 = {{1, 0}, {0, -1}} ; (*Evolución de Sz*)
```

In[∘]:=
```
Print[ Subscript["A", 0], "(t)=", MatrixForm[A2d1]]
Print[ Subscript["A", 1], "(t)=", MatrixForm[A2d2]]
Print[ Subscript["A", 2], "(t)=", MatrixForm[A2d3]]
Print[ Subscript["A", 3], "(t)=", MatrixForm[A2d4]]
```

$A_0(t) = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$

$A_1(t) = \begin{pmatrix} 0 & e^{-2 d t + i t w_1 - i t w_2} \\ e^{-2 d t - i t w_1 + i t w_2} & 0 \end{pmatrix}$

$A_2(t) = \begin{pmatrix} 0 & -i\, e^{-2 d t + i t w_1 - i t w_2} \\ i\, e^{-2 d t - i t w_1 + i t w_2} & 0 \end{pmatrix}$

$A_3(t) = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$

```
A0vector = {S0, Sx, Sy, Sz}; (*A_i(0)*)
Adtvector = {A2d1, A2d2, A2d3, A2d4}; (*A_i(t) bajo el operador de defasaje*)
Do[Do[Print["<", Subscript["A", n], "(0)", Subscript["A", m], "(t)", "> = ",
   Tr[Ro2.Adtvector[[n + 1]].A0vector[[m + 1]]]], {n, 0, 3}], {m, 0, 3}]
(* los índices del vector en mathematica van del 1 al 4,
de ahí el n+1 y el m+1 *)

(*Valores de las autocorrelaciones C_{nm}*)
```

$$<A_0(0)A_0(t)> = \frac{e^{-b w_1}}{Z} + \frac{e^{-b w_2}}{Z}$$

$$<A_1(0)A_0(t)> = 0$$

$$<A_2(0)A_0(t)> = 0$$

$$<A_3(0)A_0(t)> = \frac{e^{-b w_1}}{Z} - \frac{e^{-b w_2}}{Z}$$

$$<A_0(0)A_1(t)> = 0$$

$$<A_1(0)A_1(t)> = \frac{e^{-2 d t - b w_1 + i t w_1 - i t w_2}}{Z} + \frac{e^{-2 d t - i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_2(0)A_1(t)> = -\frac{i\, e^{-2 d t - b w_1 + i t w_1 - i t w_2}}{Z} + \frac{i\, e^{-2 d t - i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_3(0)A_1(t)> = 0$$

$$<A_0(0)A_2(t)> = 0$$

$$<A_1(0)A_2(t)> = \frac{i\, e^{-2 d t - b w_1 + i t w_1 - i t w_2}}{Z} - \frac{i\, e^{-2 d t - i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_2(0)A_2(t)> = \frac{e^{-2 d t - b w_1 + i t w_1 - i t w_2}}{Z} + \frac{e^{-2 d t - i t w_1 - b w_2 + i t w_2}}{Z}$$

$$<A_3(0)A_2(t)> = 0$$

$$<A_0(0)A_3(t)> = \frac{e^{-b w_1}}{Z} - \frac{e^{-b w_2}}{Z}$$

$$<A_1(0)A_3(t)> = 0$$

$$<A_2(0)A_3(t)> = 0$$

$$<A_3(0)A_3(t)> = \frac{e^{-b w_1}}{Z} + \frac{e^{-b w_2}}{Z}$$

```
(*Correlación normalizada A1+a.A3 para w1=3, w2=1, b=1 y d=0.2,
con la proporcion "a" tal que C2d(t)=0 en algún punto*)
```

In[∘]:= $C2d[t\_] = \left(1 + e^{-\frac{2\times 0.2\,Pi}{2}}(1)\right)^{-1}\left(\left(\frac{e^{-2\times 0.2\,t - 3\,i\,t - 1 + i\,t}}{e^{-3} + e^{-1}} + \frac{e^{-2\times 0.2\,t - 3 + 3\,i\,t - i\,t}}{e^{-3} + e^{-1}}\right) + e^{-\frac{2\times 0.2\,Pi}{2}}(1)\right)$

(*Correlación A1+a.A3 para w1=3, w2=1, b=1 y d=0,
con la proporción "a" igual al valor que tiene en C2d[t_], cuando d=0.2*)

$C2dEstable[t\_] = \left(1 + e^{-\frac{2\times 0.2\,Pi}{2}}(1)\right)^{-1}\left(\left(\frac{e^{-3\,i\,t - 1 + i\,t}}{e^{-3} + e^{-1}} + \frac{e^{-3 + 3\,i\,t - i\,t}}{e^{-3} + e^{-1}}\right) + e^{-\frac{2\times 0.2\,Pi}{2}}(1)\right)$

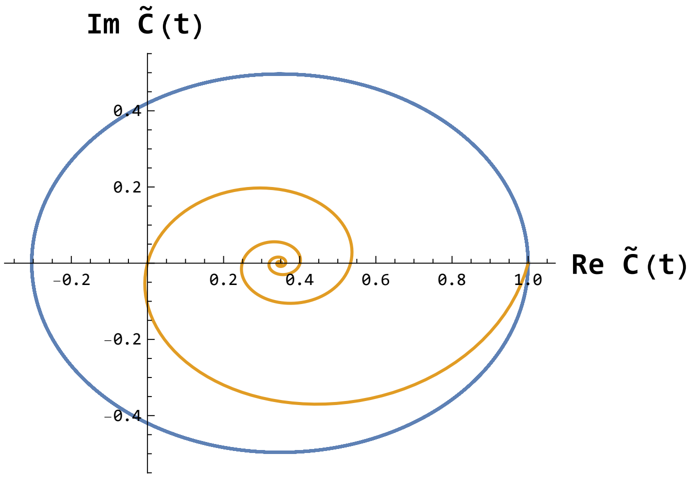
(*En amarillo, gráfica con los valores ajustados para que C2d(t) =
0 en algún punto. En azul la órbita que conseguiríamos si,
manteniendo el resto de valores inalterados, hiciesemos d=0*)

```
ParametricPlot[{{Re[C2dEstable[t]], Im[C2dEstable[t]]}, {Re[C2d[t]], Im[C2d[t]]}},
 {t, 0, 30 Pi}, AxesLabel → {Style["Re C̃(t)", Bold, 16], Style["Im C̃(t)", Bold, 16]},
 FormatType → StandardForm]
```

Out[∘]= $0.652108\left(0.533488 + \frac{e^{-1-(0.4+2.\,i)\,t}}{\frac{1}{e^3} + \frac{1}{e}} + \frac{e^{-3-(0.4-2.\,i)\,t}}{\frac{1}{e^3} + \frac{1}{e}}\right)$

Out[∘]= $0.652108\left(0.533488 + \frac{e^{-1-2\,i\,t}}{\frac{1}{e^3} + \frac{1}{e}} + \frac{e^{-3+2\,i\,t}}{\frac{1}{e^3} + \frac{1}{e}}\right)$

Out[∘]=



4.5.1.- S=1/2 con pérdidas, ganancias y defasaje - Schrödinger

```
Sminus = {{0, 0}, {1, 0}};(*operador de Linblad de pérdidas. SplusDagger*)
Splus = {{0, 1}, {0, 0}};(*operador de Linblad de ganancias. SminusDagger*)
Sz = {{1, 0}, {0, -1}};(*operador de Linblad de defasaje. SzDagger*)
H2 = {{w1, 0}, {0, w2}}; (*Hamiltoniano 2-dimensional*)
Ro = {{ro11, ro12}, {ro21, ro22}};

(*Calcular el Right Hand Side de la ecuación de Lindblad
 con pérdidas y ganancias para los cuatro componentes de Ro*)
RHSpgd11 = Simplify[(-I (H2.Ro - Ro.H2) -
       (p/2) ((Splus .Sminus .Ro) + (Ro.Splus.Sminus) - 2 (Sminus.Ro .Splus)) -
       (g/2) ((Sminus .Splus .Ro) + (Ro.Sminus .Splus) -
          (d/2) ((Sz .Sz .Ro) + (Ro.Sz.Sz) - 2 (Sz.Ro .Sz)) - 2 (Splus. Ro.Sminus))) [[
     1, 1]] , {p ∈ Reals, g ∈ Reals, d ∈ Reals}];
RHSpgd12 = Simplify[(-I (H2.Ro - Ro.H2)
       - (p/2) ((Splus .Sminus .Ro) + (Ro.Splus.Sminus) - 2 (Sminus.Ro .Splus))
       - (g/2) ((Sminus .Splus .Ro) + (Ro.Sminus .Splus) - 2 (Splus.Ro .Sminus))
       - (d/2) ((Sz .Sz .Ro) + (Ro.Sz.Sz) - 2 (Sz.Ro .Sz))) [[1, 2]] ,
    {p ∈ Reals, g ∈ Reals, d ∈ Reals}];
RHSpgd21 = Simplify[(-I (H2.Ro - Ro.H2)
       - (p/2) ((Splus .Sminus .Ro) + (Ro.Splus.Sminus) - 2 (Sminus.Ro .Splus))
       - (g/2) ((Sminus .Splus .Ro) + (Ro.Sminus .Splus) - 2 (Splus.Ro .Sminus))
       - (d/2) ((Sz .Sz .Ro) + (Ro.Sz.Sz) - 2 (Sz.Ro .Sz))) [[2, 1]] ,
    {p ∈ Reals, g ∈ Reals, d ∈ Reals}];
RHSpgd22 = Simplify[(-I (H2.Ro - Ro.H2) -
       (p/2) ((Splus .Sminus .Ro) + (Ro.Splus.Sminus) - 2 (Sminus.Ro .Splus)) -
       (g/2) ((Sminus .Splus .Ro) + (Ro.Sminus .Splus) -
          (d/2) ((Sz .Sz .Ro) + (Ro.Sz.Sz) - 2 (Sz.Ro .Sz)) - 2 (Splus. Ro.Sminus))) [[
     2, 2]] , {p ∈ Reals, g ∈ Reals, d ∈ Reals}];
```

```
In[∘]:= (*Left Hand Side = Right Hand Side. Las ecuaciones que
   surgen para cada componente de Ro de la ecuación de Lindblad*)
Print[Subscript["Ro'", 11], "(t)=", RHSpgd11]
Print[Subscript["Ro'", 12], "(t)=", RHSpgd12]
Print[Subscript["Ro'", 21], "(t)=", RHSpgd21]
Print[Subscript["Ro'", 22], "(t)=", RHSpgd22]
```

$Ro'_{11}(t) = -p\, ro_{11} + g\, ro_{22}$

$Ro'_{12}(t) = -\frac{1}{2} ro_{12} (4 d + g + p + 2 i w_1 - 2 i w_2)$

$Ro'_{21}(t) = -\frac{1}{2} ro_{21} (4 d + g + p - 2 i w_1 + 2 i w_2)$

$Ro'_{22}(t) = p\, ro_{11} - g\, ro_{22}$

```
(*Resolución de las acuaciones
 diferenciales acopladas obtenidas en el paso anterior*)
```

In[ ]:=
```
DSolve[{ro11'[t] == -p ro11[t] + g ro22[t],
  ro12'[t] == 1/2 ro12[t] (-4 d - g - p - 2 I w1 + 2 I w2),
  ro21'[t] == 1/2 ro21[t] (-4 d - g - p + 2 I w1 - 2 I w2), ro22'[t] == p ro11[t] - g ro22[t]},
 {ro11[t], ro12[t], ro21[t], ro22[t]} , t]
```

Out[ ]=

$$\left\{\left\{ro11[t] \to \frac{\left(g + e^{(-g-p)\,t}\,p\right) C[1]}{g+p} - \frac{\left(-1 + e^{(-g-p)\,t}\right) g\,C[2]}{g+p},\right.\right.$$

$$ro22[t] \to -\frac{\left(-1 + e^{(-g-p)\,t}\right) p\,C[1]}{g+p} + \frac{\left(e^{(-g-p)\,t}\,g + p\right) C[2]}{g+p},$$

$$\left.\left. ro12[t] \to e^{-2\,d\,t-\frac{g\,t}{2}-\frac{p\,t}{2}-i\,t\,w_1+i\,t\,w_2}\,C[3],\ ro21[t] \to e^{-2\,d\,t-\frac{g\,t}{2}-\frac{p\,t}{2}+i\,t\,w_1-i\,t\,w_2}\,C[4]\right\}\right\}$$

4.5.2.- S=1/2 con pérdidas, ganancias y defasaje - Heisenberg

```
S0 = {{1, 0}, {0, 1}} ; (*Identidad 2x2*)
Sx = {{0, 1}, {1, 0}} ; (*Sigma x*)
Sy = {{0, -I}, {I, 0}} ; (*Sigma y*)
Sz = {{1, 0}, {0, -1}} ; (*Sigma z. operador de Linblad de defasaje. SzDagger*)
Sminus = {{0, 0}, {1, 0}}; (*operador de Linblad de pérdidas. SplusDagger*)
Splus = {{0, 1}, {0, 0}};(*operador de Linblad de ganancias. SminusDagger*)
A = {{a11, a12}, {a21, a22}};
H2 = {{w1, 0}, {0, w2}}; (*Hamiltoniano 2-dimensional*)
Ro2 = 1 / Z {{Exp[-b w1], 0}, {0, Exp[-b w2]}};
(*Matriz de densidad 2x2, constante en esta imagen*)


(*Calcular el Right Hand Side de la ecuación de Lindblad con pérdidas
 ganancias y defasaje para los cuatro componentes de un A genérico*)
RHSpgd11 = Simplify[(
      I (H2.A - A.H2)
       - (p / 2) ((Splus .Sminus .A) + (A.Splus .Sminus) - 2 (Splus. A.Sminus))
       - (g / 2) ((Sminus .Splus .A) + (A.Sminus .Splus)  - 2 (Sminus. A.Splus))
       - (d / 2) ((Sz .Sz .A) + (A.Sz .Sz)  - 2 (Sz. A.Sz))
     )[[1, 1]] , {p ∈ Reals, g ∈ Reals, d ∈ Reals}];
RHSpgd12 = Simplify[(
      I (H2.A - A.H2)
       - (p / 2) ((Splus .Sminus .A) + (A.Splus .Sminus) - 2 (Splus. A.Sminus))
       - (g / 2) ((Sminus .Splus .A) + (A.Sminus .Splus)  - 2 (Sminus. A.Splus))
       - (d / 2) ((Sz .Sz .A) + (A.Sz .Sz)  - 2 (Sz. A.Sz))
     )[[1, 2]] , {p ∈ Reals, g ∈ Reals, d ∈ Reals}];
RHSpgd21 = Simplify[(
      I (H2.A - A.H2)
       - (p / 2) ((Splus .Sminus .A) + (A.Splus .Sminus) - 2 (Splus. A.Sminus))
       - (g / 2) ((Sminus .Splus .A) + (A.Sminus .Splus)  - 2 (Sminus. A.Splus))
       - (d / 2) ((Sz .Sz .A) + (A.Sz .Sz)  - 2 (Sz. A.Sz))
     )[[2, 1]] , {p ∈ Reals, g ∈ Reals, d ∈ Reals}];
RHSpgd22 = Simplify[(
      I (H2.A - A.H2)
       - (p / 2) ((Splus .Sminus .A) + (A.Splus .Sminus) - 2 (Splus. A.Sminus))
       - (g / 2) ((Sminus .Splus .A) + (A.Sminus .Splus)  - 2 (Sminus. A.Splus))
       - (d / 2) ((Sz .Sz .A) + (A.Sz .Sz)  - 2 (Sz. A.Sz))
     )[[2, 2]] , {p ∈ Reals, g ∈ Reals, d ∈ Reals}];
```

```
(*Left Hand Side = Right Hand Side. Las ecuaciones que
  surgen para cada componente de A de la ecuación de Lindblad*)
Print[Subscript["a'", 11], "(t)=", RHSpgd11]
Print[Subscript["a'", 12], "(t)=", RHSpgd12]
Print[Subscript["a'", 21], "(t)=", RHSpgd21]
Print[Subscript["a'", 22], "(t)=", RHSpgd22]
```

$a'_{11}(t) = p\,(-a_{11} + a_{22})$

$a'_{12}(t) = -\frac{1}{2} a_{12}\,(4\,d + g + p - 2\,i\,w_1 + 2\,i\,w_2)$

$a'_{21}(t) = -\frac{1}{2} a_{21}\,(4\,d + g + p + 2\,i\,w_1 - 2\,i\,w_2)$

$a'_{22}(t) = g\,(a_{11} - a_{22})$

In[∘]:=
```
(*Resolución de las acuaciones diferenciales
 acopladas obtenidas en el paso anterior*)
DSolve[{a11'[t] == p (-a11[t] + a22[t]),
  a12'[t] == -1/2 a12[t] (4 d + g + p - 2 I w1 + 2 I w2),
  a21'[t] ==-1/2 a21[t] (4 d + g + p + 2 I w1 - 2 I w2),
  a22'[t] == g (a11[t] - a22[t])},
 {a11[t], a12[t], a21[t], a22[t]} , t]
```

Out[∘]=
$$\left\{\left\{a11[t] \to \frac{\left(g + e^{(-g-p)\,t}\,p\right) C[1]}{g+p} - \frac{\left(-1 + e^{(-g-p)\,t}\right) p\,C[2]}{g+p},\right.\right.$$
$$a22[t] \to -\frac{\left(-1 + e^{(-g-p)\,t}\right) g\,C[1]}{g+p} + \frac{\left(e^{(-g-p)\,t}\,g + p\right) C[2]}{g+p},$$
$$\left.\left. a12[t] \to e^{-2\,d\,t - \frac{g\,t}{2} - \frac{p\,t}{2} + i\,t\,w_1 - i\,t\,w_2}\,C[3],\ a21[t] \to e^{-2\,d\,t - \frac{g\,t}{2} - \frac{p\,t}{2} - i\,t\,w_1 + i\,t\,w_2}\,C[4]\right\}\right\}$$

```
A2pgd1 = {{1, 0}, {0, 1}} ;
(*Evolución de la identidad 2x2 bajo operadores de pérdidas ganancias y defasaje,
teniendo en cuenta su forma en t=0*)
```

$$A2pgd2 = \left\{\left\{0,\ e^{-2\,d\,t - \frac{g\,t}{2} - \frac{p\,t}{2} + I\,t\,w_1 - I\,t\,w_2}\right\},\ \left\{e^{-2\,d\,t - \frac{g\,t}{2} - \frac{p\,t}{2} - I\,t\,w_1 + I\,t\,w_2},\ 0\right\}\right\};\ \text{(*Evolución de Sx*)}$$

$$A2pgd3 = \left\{\left\{0,\ -I\,e^{-2\,d\,t - \frac{g\,t}{2} - \frac{p\,t}{2} + I\,t\,w_1 - I\,t\,w_2}\right\},\ \left\{I\,e^{-2\,d\,t - \frac{g\,t}{2} - \frac{p\,t}{2} - I\,t\,w_1 + I\,t\,w_2},\ 0\right\}\right\};\ \text{(*Evolución de Sy*)}$$

$$A2pgd4 = \left\{\left\{\frac{g - p + 2\,e^{(-g-p)\,t}\,p}{g+p},\ 0\right\},\ \left\{0,\ \frac{g - p - 2\,e^{(-g-p)\,t}\,g}{g+p}\right\}\right\};\ \text{(*Evolución de Sz*)}$$

In[∘]:=
```
Print[ Subscript["A", 0], "(t)=", MatrixForm[A2pgd1]]
Print[ Subscript["A", 1], "(t)=", MatrixForm[A2pgd2]]
Print[ Subscript["A", 2], "(t)=", MatrixForm[A2pgd3]]
Print[ Subscript["A", 3], "(t)=", MatrixForm[A2pgd4]]
```

$$A_0(t) = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

$$A_1(t) = \begin{pmatrix} 0 & e^{-2\,d\,t - \frac{g\,t}{2} - \frac{p\,t}{2} + i\,t\,w_1 - i\,t\,w_2} \\ e^{-2\,d\,t - \frac{g\,t}{2} - \frac{p\,t}{2} - i\,t\,w_1 + i\,t\,w_2} & 0 \end{pmatrix}$$

$$A_2(t) = \begin{pmatrix} 0 & -i\,e^{-2\,d\,t - \frac{g\,t}{2} - \frac{p\,t}{2} + i\,t\,w_1 - i\,t\,w_2} \\ i\,e^{-2\,d\,t - \frac{g\,t}{2} - \frac{p\,t}{2} - i\,t\,w_1 + i\,t\,w_2} & 0 \end{pmatrix}$$

$$A_3(t) = \begin{pmatrix} \frac{g-p+2\,e^{(-g-p)\,t}\,p}{g+p} & 0 \\ 0 & \frac{g-2\,e^{(-g-p)\,t}\,g-p}{g+p} \end{pmatrix}$$

```
A0vector = {S0, Sx, Sy, Sz}; (*A_i(0)*)
Apgdtvector = {A2pgd1, A2pgd2, A2pgd3, A2pgd4};
(*A_i(t) bajo el operador de pérdidas ganancias y defasaje*)
Do[Do[Print["<", Subscript["A", n], "(0)", Subscript["A", m], "(t)", "> = ",
   Tr[Ro2.Apgdtvector[[n + 1]].A0vector[[m + 1]]]], {n, 0, 3}], {m, 0, 3}]
(* los índices del vector en mathematica van del 1 al 4,
de ahí el n+1 y el m+1 *)

(*Valores de las autocorrelaciones C_{nm}*)
```

$$\langle A_0(0) A_0(t)\rangle = \frac{e^{-b w_1}}{Z} + \frac{e^{-b w_2}}{Z}$$

$$\langle A_1(0) A_0(t)\rangle = 0$$

$$\langle A_2(0) A_0(t)\rangle = 0$$

$$\langle A_3(0) A_0(t)\rangle = \frac{e^{-b w_2}\left(g - 2 e^{(-g-p)\,t} g - p\right)}{(g+p)\,Z} + \frac{e^{-b w_1}\left(g - p + 2 e^{(-g-p)\,t} p\right)}{(g+p)\,Z}$$

$$\langle A_0(0) A_1(t)\rangle = 0$$

$$\langle A_1(0) A_1(t)\rangle = \frac{e^{-2 d t-\frac{g t}{2}-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} + \frac{e^{-2 d t-\frac{g t}{2}-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$\langle A_2(0) A_1(t)\rangle = -\frac{i\, e^{-2 d t-\frac{g t}{2}-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} + \frac{i\, e^{-2 d t-\frac{g t}{2}-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$\langle A_3(0) A_1(t)\rangle = 0$$

$$\langle A_0(0) A_2(t)\rangle = 0$$

$$\langle A_1(0) A_2(t)\rangle = \frac{i\, e^{-2 d t-\frac{g t}{2}-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} - \frac{i\, e^{-2 d t-\frac{g t}{2}-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$\langle A_2(0) A_2(t)\rangle = \frac{e^{-2 d t-\frac{g t}{2}-\frac{p t}{2}-b w_1+i t w_1-i t w_2}}{Z} + \frac{e^{-2 d t-\frac{g t}{2}-\frac{p t}{2}-i t w_1-b w_2+i t w_2}}{Z}$$

$$\langle A_3(0) A_2(t)\rangle = 0$$

$$\langle A_0(0) A_3(t)\rangle = \frac{e^{-b w_1}}{Z} - \frac{e^{-b w_2}}{Z}$$

$$\langle A_1(0) A_3(t)\rangle = 0$$

$$\langle A_2(0) A_3(t)\rangle = 0$$

$$\langle A_3(0) A_3(t)\rangle = -\frac{e^{-b w_2}\left(g - 2 e^{(-g-p)\,t} g - p\right)}{(g+p)\,Z} + \frac{e^{-b w_1}\left(g - p + 2 e^{(-g-p)\,t} p\right)}{(g+p)\,Z}$$

```
(*Correlación normalizada A1+a.A3 para w1=3, w2=1, b=1, p=0.2,
g=0.2, d=0.2, con la proporcion "a" tal que C2pg(t)=0 en algún punto*)
```

In[•]:= C2pgt[t_] =

$$\left((1)+\left(\left(\left(e^{-\frac{2\times0.2\,\mathrm{Pi}}{2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-1}+e^{-\frac{2\times0.2\,\mathrm{Pi}}{2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-3}\right)\Big/\left(\frac{1}{(0.2+0.2)}\left(e^{-1}\left(0.2-2\,e^{(-0.2-0.2)\frac{\mathrm{Pi}}{2}}\,0.2-0.2\right)+e^{-3}\left(0.2-0.2+2\,e^{(-0.2-0.2)\frac{\mathrm{Pi}}{2}}\,0.2\right)\right)\right)\right)\left(\frac{e^{-1}\left(0.2-2\times0.2-0.2\right)}{(0.2+0.2)\left(e^{-3}+e^{-1}\right)}+\frac{e^{-3}\left(0.2-0.2+2\times0.2\right)}{(0.2+0.2)\left(e^{-3}+e^{-1}\right)}\right)\right)\right)^{-1}$$

$$\left(\left(\frac{e^{-2\times0.2\,t-\frac{0.2\,t}{2}-\frac{0.2\,t}{2}-3\,i\,t-1+i\,t}}{e^{-3}+e^{-1}}+\frac{e^{-2\times0.2\,t-\frac{0.2\,t}{2}-\frac{0.2\,t}{2}-3+3\,i\,t-i\,t}}{e^{-3}+e^{-1}}\right)+\left(\left(e^{-\frac{2\times0.2\,\mathrm{Pi}}{2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-1}+e^{-\frac{2\times0.2\,\mathrm{Pi}}{2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-3}\right)\Big/\left(\frac{1}{(0.2+0.2)}\left(e^{-1}\left(0.2-2\,e^{(-0.2-0.2)\frac{\mathrm{Pi}}{2}}\,0.2-0.2\right)+e^{-3}\left(0.2-0.2+2\,e^{(-0.2-0.2)\frac{\mathrm{Pi}}{2}}\,0.2\right)\right)\right)\right)\left(\frac{e^{-1}\left(0.2-2\,e^{(-0.2-0.2)\,t}\,0.2-0.2\right)}{(0.2+0.2)\left(e^{-3}+e^{-1}\right)}+\frac{e^{-3}\left(0.2-0.2+2\,e^{(-0.2-0.2)\,t}\,0.2\right)}{(0.2+0.2)\left(e^{-3}+e^{-1}\right)}\right)\right)$$

```
(*Correlación A1+a.A3 para w1=3, w2=1, b=1, p=0, g=0, d=0,
con la proporción "a" igual al valor que tiene en C2pgd[t_],
cuando p=0.2 g=0.2 y d=0.2*)
C2pgtEstable[t_] =
```

$$\left((1)+\left(\left(e^{-\frac{2\times0.2\,\mathrm{Pi}}{2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-1}+e^{-\frac{2\times0.2\,\mathrm{Pi}}{2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-3}\right)\Big/\left(\frac{1}{(0.2+0.2)}\left(e^{-1}\left(0.2-2\,e^{(-0.2-0.2)\frac{\mathrm{Pi}}{2}}\,0.2-0.2\right)+e^{-3}\left(0.2-0.2+2\,e^{(-0.2-0.2)\frac{\mathrm{Pi}}{2}}\,0.2\right)\right)\right)\right)\frac{e^{-3}-e^{-1}}{\left(e^{-3}+e^{-1}\right)}\right)^{-1}$$

$$\left(\left(\frac{e^{-3\,i\,t-1+i\,t}}{e^{-3}+e^{-1}}+\frac{e^{-3+3\,i\,t-i\,t}}{e^{-3}+e^{-1}}\right)+\left(\left(e^{-\frac{2\times0.2\,\mathrm{Pi}}{2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-1}+e^{-\frac{2\times0.2\,\mathrm{Pi}}{2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-\frac{0.2\,\mathrm{Pi}}{2\times2}-3}\right)\Big/\left(\frac{1}{(0.2+0.2)}\left(e^{-1}\left(0.2-2\,e^{(-0.2-0.2)\frac{\mathrm{Pi}}{2}}\,0.2-0.2\right)+e^{-3}\left(0.2-0.2+2\,e^{(-0.2-0.2)\frac{\mathrm{Pi}}{2}}\,0.2\right)\right)\right)\right)\frac{e^{-3}-e^{-1}}{\left(e^{-3}+e^{-1}\right)}\right)$$

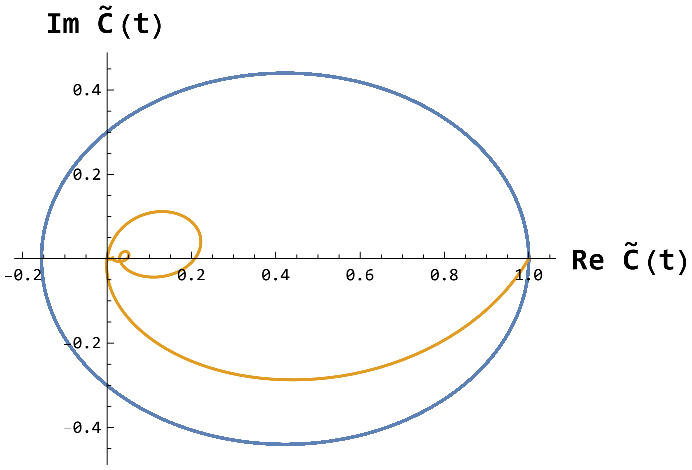
```
(*En amarillo, gráfica con los valores ajustados para que C2p(t)=
 0 en algún punto. En azul la órbita que conseguiríamos si,
manteniendo el resto de valores inalterados, hiciesemos p=g=d=0*)
ParametricPlot[
 {{Re[C2pgtEstable[t]], Im[C2pgtEstable[t]]}, {Re[C2pgt[t]], Im[C2pgt[t]]}},
 {t, 0, 30 Pi}, AxesLabel → {Style["Re C̃(t)" , Bold, 16], Style["Im C̃(t)", Bold, 16]},
 FormatType → StandardForm]
```

Out[•]=

$$0.5779\left(\frac{e^{-1-(0.6+2.\,i)\,t}}{\frac{1}{e^{3}}+\frac{1}{e}}+\frac{e^{-3-(0.6-2.\,i)\,t}}{\frac{1}{e^{3}}+\frac{1}{e}}-0.959045\left(2.20199\left(0.-0.4\,e^{-0.4\,t}\right)+0.298007\left(0.+0.4\,e^{-0.4\,t}\right)\right)\right)$$

Out[ ]= $0.5779 \left(0.730403 + \frac{e^{-1-2 i t}}{\frac{1}{e^3} + \frac{1}{e}} + \frac{e^{-3+2 i t}}{\frac{1}{e^3} + \frac{1}{e}}\right)$

Out[ ]=



4.5.2.- Manipulable de S=1/2 con 6 parámetros (pérdidas, ganancias, defasaje, temperatura y energías variables)

In[9]:=

$$\text{apgd6}[p\_, g\_, d\_, b\_, w1\_, w2\_] := (g+p)\, e^{\frac{-(4d+g+p)\frac{Pi}{w1-w2}}{2}} \left(e^{-b\,w1}+e^{-b\,w2}\right)\left(-e^{-b\,w2}\left(g-p-2\,g\,e^{-(g+p)\frac{Pi}{w1-w2}}\right)+e^{-b\,w1}\left(g-p+2\,p\,e^{-(g+p)\frac{Pi}{w1-w2}}\right)\right)^{-1};$$

(*proporción alfa con los 6 parámetros*)

$$\text{C2pgd6}[t\_, p\_, g\_, d\_, b\_, w1\_, w2\_] := \left(\frac{e^{\frac{-(4d+p+g)\,t}{2}-i\,t\,w1-b\,w2+i\,t\,w2}}{\left(e^{-b\,w1}+e^{-b\,w2}\right)}+\frac{e^{\frac{-(4d+p+g)\,t}{2}-b\,w1+i\,t\,w1-i\,t\,w2}}{\left(e^{-b\,w1}+e^{-b\,w2}\right)}\right)+ \left(\text{apgd6}[p, g, d, b, w1, w2]\right)\left(-\frac{e^{-b\,w2}\left(g-p-2\,e^{-(p+g)\,t}\,g\right)}{(p+g)\left(e^{-b\,w1}+e^{-b\,w2}\right)}+\frac{e^{-b\,w1}\left(g-p+2\,e^{-(p+g)\,t}\,p\right)}{(p+g)\left(e^{-b\,w1}+e^{-b\,w2}\right)}\right);$$

(*Correlación A1+apgd6.A3 para 6 variables + el tiempo*)

$$\text{C2pgd6Estable}[t\_, p\_, g\_, d\_, b\_, w1\_, w2\_] := \left(\frac{e^{-i\,t\,w2-b\,w1+i\,t\,w1}}{\left(e^{-b\,w1}+e^{-b\,w2}\right)}+\frac{e^{-i\,t\,w1-b\,w2+i\,t\,w2}}{\left(e^{-b\,w1}+e^{-b\,w2}\right)}\right)+\left(\text{apgd6}[p, g, d, b, w1, w2]\right);$$

```
Manipulate[ParametricPlot[
  {{Re[C2pgd6Estable[t, p, g, d, b, w1, w2] / C2pgd6Estable[0, p, g, d, b, w1, w2]], Im[C2pgd6Estable[t, p, g, d, b, w1, w2] / C2pgd6Estable[0, p, g, d, b, w1, w2]]},
   {Re[C2pgd6[t, p, g, d, b, w1, w2] / C2pgd6[0, p, g, d, b, w1, w2]], Im[C2pgd6[t, p, g, d, b, w1, w2] / C2pgd6[0, p, g, d, b, w1, w2]]}}, {t, 0, 5 Pi},
  AxesLabel → {Style["Re C̃(t)", Bold, 16], Style["Im C̃(t)", Bold, 16]},
  FormatType → StandardForm], {p, 0, 2}, {g, 0.0000001, 3},
 {d, 0, 0.5}, {b, 0.5, 1.5}, {w1, 1, 5}, {w2, 0, w1}]
```

Out[12]=