```
(*******************************************************)
(* Bennett Mechanism Reaction Solvability Analysis (RSA) *)
(* Using Natural Coordinates *)
(*******************************************************)
SetOptions[EvaluationNotebook[], CellContext → Notebook]

MyNorm[a_] := a[[1]]^2 + a[[2]]^2 + a[[3]]^2

Do[(r_j = {x_j, y_j, z_j}), {j, 8}]
Do[(u_j = {e_j, f_j, g_j}), {j, 8}]
Q = Join[r_1, r_2, r_3, r_4, r_5, r_6, r_7, r_8, u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8];

(*Constraint Equations*)
R1 = Join[r_2 - r_3, u_2 - u_3];
R2 = Join[r_4 - r_5, u_4 - u_5];
R3 = Join[r_6 - r_7, u_6 - u_7];
R4 = Join[r_8 - r_1, u_8 - u_1];
Φ = Join[R1, R2, R3, R4];
(*Adding 8 Unit vector constraints*)
Do[(Φ = Join[Φ, {MyNorm[u_j] - 1}]), {j, 8}]

(*Adding Rigid link constraints*)
Do[(Φ = Join[Φ, {(r_{j+1} - r_j).u_j}]), {j, 1, 7, 2}]
Do[(Φ = Join[Φ, {(r_{j+1} - r_j).u_{j+1}}]), {j, 1, 7, 2}]
Do[(Φ = Join[Φ, {MyNorm[r_{j+1} - r_j] - a^2}]), {j, 1, 7, 2}]
Do[(Φ = Join[Φ, {u_j.u_{j+1} - Cos[α_j]}]), {j, 1, 7, 2}]

(*Adding Fixind(Ground) constraints*)
Φ = Join[Φ, r_1];
Φ = Join[Φ, r_2 - {p, q, t}];

Φ // MatrixForm
```

$$\begin{pmatrix} x_2 - x_3 \\ y_2 - y_3 \\ z_2 - z_3 \\ e_2 - e_3 \\ f_2 - f_3 \\ g_2 - g_3 \\ x_4 - x_5 \\ y_4 - y_5 \\ z_4 - z_5 \\ e_4 - e_5 \\ f_4 - f_5 \\ g_4 - g_5 \\ x_6 - x_7 \\ y_6 - y_7 \\ z_6 - z_7 \end{pmatrix}$$

$$\begin{pmatrix}
e_6 - e_7 \\
f_6 - f_7 \\
g_6 - g_7 \\
-x_1 + x_8 \\
-y_1 + y_8 \\
-z_1 + z_8 \\
-e_1 + e_8 \\
-f_1 + f_8 \\
-g_1 + g_8 \\
-1 + e_1^2 + f_1^2 + g_1^2 \\
-1 + e_2^2 + f_2^2 + g_2^2 \\
-1 + e_3^2 + f_3^2 + g_3^2 \\
-1 + e_4^2 + f_4^2 + g_4^2 \\
-1 + e_5^2 + f_5^2 + g_5^2 \\
-1 + e_6^2 + f_6^2 + g_6^2 \\
-1 + e_7^2 + f_7^2 + g_7^2 \\
-1 + e_8^2 + f_8^2 + g_8^2 \\
e_1 (-x_1 + x_2) + f_1 (-y_1 + y_2) + g_1 (-z_1 + z_2) \\
e_3 (-x_3 + x_4) + f_3 (-y_3 + y_4) + g_3 (-z_3 + z_4) \\
e_5 (-x_5 + x_6) + f_5 (-y_5 + y_6) + g_5 (-z_5 + z_6) \\
e_7 (-x_7 + x_8) + f_7 (-y_7 + y_8) + g_7 (-z_7 + z_8) \\
e_2 (-x_1 + x_2) + f_2 (-y_1 + y_2) + g_2 (-z_1 + z_2) \\
e_4 (-x_3 + x_4) + f_4 (-y_3 + y_4) + g_4 (-z_3 + z_4) \\
e_6 (-x_5 + x_6) + f_6 (-y_5 + y_6) + g_6 (-z_5 + z_6) \\
e_8 (-x_7 + x_8) + f_8 (-y_7 + y_8) + g_8 (-z_7 + z_8) \\
-a^2 + (-x_1 + x_2)^2 + (-y_1 + y_2)^2 + (-z_1 + z_2)^2 \\
-a^2 + (-x_3 + x_4)^2 + (-y_3 + y_4)^2 + (-z_3 + z_4)^2 \\
-a^2 + (-x_5 + x_6)^2 + (-y_5 + y_6)^2 + (-z_5 + z_6)^2 \\
-a^2 + (-x_7 + x_8)^2 + (-y_7 + y_8)^2 + (-z_7 + z_8)^2 \\
-\mathrm{Cos}[\alpha_1] + e_1 e_2 + f_1 f_2 + g_1 g_2 \\
-\mathrm{Cos}[\alpha_3] + e_3 e_4 + f_3 f_4 + g_3 g_4 \\
-\mathrm{Cos}[\alpha_5] + e_5 e_6 + f_5 f_6 + g_5 g_6 \\
-\mathrm{Cos}[\alpha_7] + e_7 e_8 + f_7 f_8 + g_7 g_8 \\
x_1 \\
y_1 \\
z_1 \\
-p + x_2 \\
-q + y_2 \\
-t + z_2
\end{pmatrix}$$

```
J = D[Φ, {Q}] (* Jacobian Matrix *)
```

```
{{0, 0, 0, 1, 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, 1, 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, 1, 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, 1, 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, 1, 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, 1, 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, 1, 0, 0, -1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
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{0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 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, 1, 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, 1, 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, 1, 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, 1, 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},
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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, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0,
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{0, 0, -1, 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, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
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0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0},
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-1, 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, 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, 0, 0, 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, $2 e_1$,
$2 f_1$, $2 g_1$, 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, $2 e_2$, $2 f_2$, $2 g_2$, 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, $2 e_3$, $2 f_3$, $2 g_3$, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
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0, 0, 0, 0, 0, 0, 0, $2 e_4$, $2 f_4$, $2 g_4$, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
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{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, $2 e_6$, $2 f_6$, $2 g_6$, 0, 0, 0, 0, 0, 0},
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0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, $2 e_7$, $2 f_7$, $2 g_7$, 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, $2 e_8$, $2 f_8$, $2 g_8$},
{$-e_1$, $-f_1$, $-g_1$, e_1, f_1, g_1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
$-x_1 + x_2$, $-y_1 + y_2$, $-z_1 + z_2$, 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, $-e_3$, $-f_3$, $-g_3$, e_3, f_3, g_3, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, $-x_3 + x_4$, $-y_3 + y_4$, $-z_3 + z_4$, 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, $-e_5$, $-f_5$, $-g_5$, e_5, f_5, g_5, 0, 0, 0, 0, 0, 0, 0,
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{0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, $-e_7$, $-f_7$, $-g_7$, e_7, f_7, g_7, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, $-x_7 + x_8$, $-y_7 + y_8$, $-z_7 + z_8$, 0, 0, 0},
{$-e_2$, $-f_2$, $-g_2$, e_2, f_2, g_2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, $-x_1 + x_2$, $-y_1 + y_2$, $-z_1 + z_2$, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
{0, 0, 0, 0, 0, 0, $-e_4$, $-f_4$, $-g_4$, e_4, f_4, g_4, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
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{0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, $-e_6$, $-f_6$, $-g_6$, e_6, f_6, g_6, 0, 0, 0, 0, 0, 0, 0,
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{0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, $-e_8$, $-f_8$, $-g_8$, e_8, f_8, g_8, 0,
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, $-x_7 + x_8$, $-y_7 + y_8$, $-z_7 + z_8$},
{$-2 (-x_1 + x_2)$, $-2 (-y_1 + y_2)$, $-2 (-z_1 + z_2)$, $2 (-x_1 + x_2)$, $2 (-y_1 + y_2)$,
$2 (-z_1 + z_2)$, 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, $-2 (-x_3 + x_4)$, $-2 (-y_3 + y_4)$, $-2 (-z_3 + z_4)$, $2 (-x_3 + x_4)$,
$2 (-y_3 + y_4)$, $2 (-z_3 + z_4)$, 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, $-2 (-x_5 + x_6)$, $-2 (-y_5 + y_6)$, $-2 (-z_5 + z_6)$,
$2 (-x_5 + x_6)$, $2 (-y_5 + y_6)$, $2 (-z_5 + z_6)$, 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, $-2 (-x_7 + x_8)$,
$-2 (-y_7 + y_8)$, $-2 (-z_7 + z_8)$, $2 (-x_7 + x_8)$, $2 (-y_7 + y_8)$, $2 (-z_7 + z_8)$,
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, e_2,
f_2, g_2, e_1, f_1, g_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, e_4, f_4, g_4, e_3, f_3, g_3, 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, e_6, f_6, g_6, e_5, f_5, g_5, 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, e_8, f_8, g_8, e_7, f_7, g_7},
{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},
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0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
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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, 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, 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}}
```

```
MatrixRank[J]
```

```
48
```

```
Dimensions[J]
```

```
{54, 48}
```

```
RSA[cList_] := (J^i = J[[cList, All]]; J^-i = Complement[J, J^i];
  Print["J^i = ", MatrixRank[J^i], " and J^-i = ", MatrixRank[J^-i]];)
```

```
RSA[{1, 2, 3, 4, 5, 6}]
```

```
J^i = 6 and J^-i = 47
```