Quantum Information with Solid-State Devices

VO 141.246

Dr. Johannes Majer

Lecture 6

Quantum Information with Solid-state Devices

News

The next class (3. May) will start at the regular time **14:00** at the Raum der Fachgruppe.

Lecture Notes

15 March 2010 - Lecture 1 Introduction

QISS Lecture Notes 1.pdf

22 March 2010 - Lecture 2

QISS Lecture 2 Notes.pdf
QISS Lecture 2 Slides.pdf
Matlab Lecture 2.zip

12 April 2010 - Lecture 3

QISS Lecture 3 Notes.pdf
QISS Lecture 3 Slides.pdf

19 April 2010 - Lecture 4

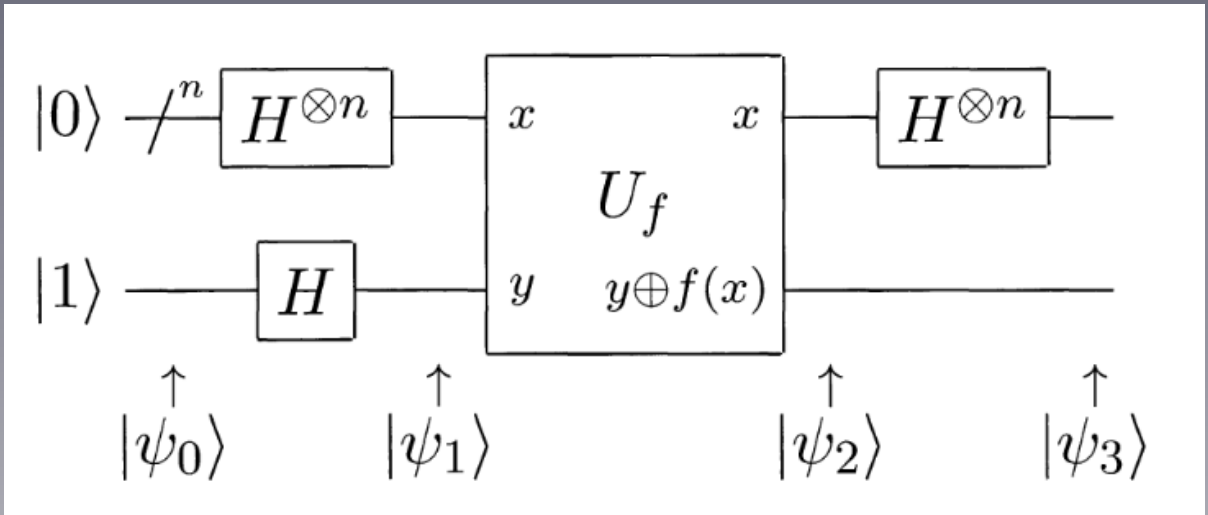
QISS Lecture 4 Notes.pdf
Matlab Lecture 4.zip

26 April 2010 - Lecture 5

QISS Lecture 5 Notes.pdf

Lecture Announcement

Deutsch-Josza

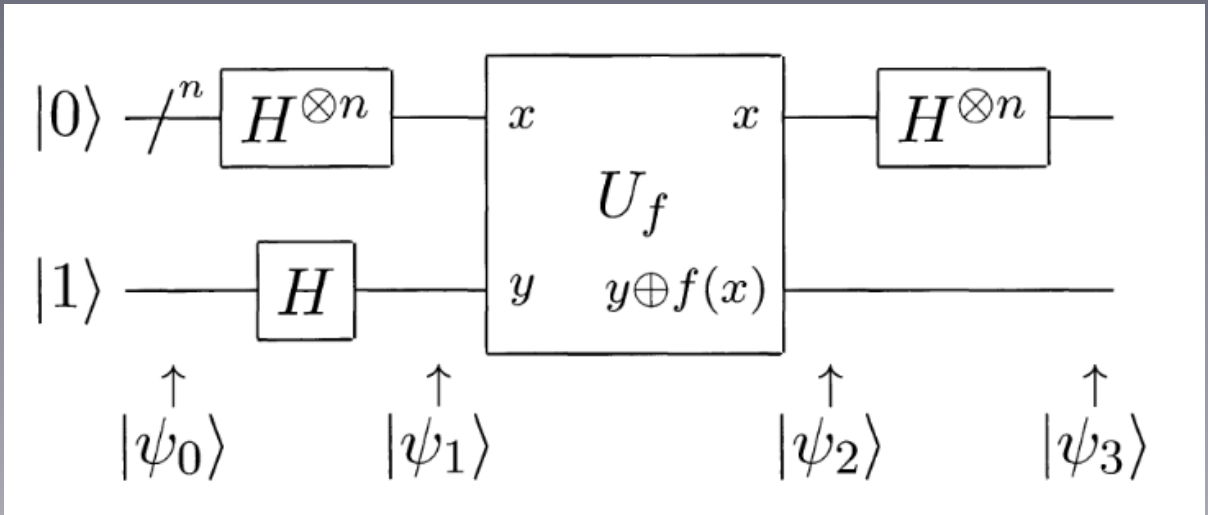



```
%% Implementation of Uf
%constant function
Ufconst0 = [1 0 0 0 0 0 0 0;...
            0 1 0 0 0 0 0 0;...
            0 0 1 0 0 0 0 0;...
            0 0 0 1 0 0 0 0;...
            0 0 0 0 1 0 0 0;...
            0 0 0 0 0 1 0 0;...
            0 0 0 0 0 0 1 0;...
            0 0 0 0 0 0 0 1];
```

```
%%
psi0 = kron([1 0 0 0]',[0 1]')

psi0 =

     0
     1
     0
     0
     0
     0
     0
     0


psi1 = kron(Had2,id)*kron(id2,Had)*psi0

psi1 =

    0.3536
   -0.3536
    0.3536
   -0.3536
    0.3536
   -0.3536
    0.3536
   -0.3536
```

```
psi2 = Uf*psi1

psi2 =

    0.3536
   -0.3536
    0.3536
   -0.3536
    0.3536
   -0.3536
    0.3536
   -0.3536


psi3 = kron(Had2,id)*psi2

psi3 =

    0.7071
   -0.7071
         0
         0
         0
         0
         0
         0


sz1 = psi3'*kron(kron(sigma_z,id),id)*psi3

sz1 =

    1.0000

sz2 = psi3'*kron(kron(id,sigma_z),id)*psi3

sz2 =

    1.0000
```

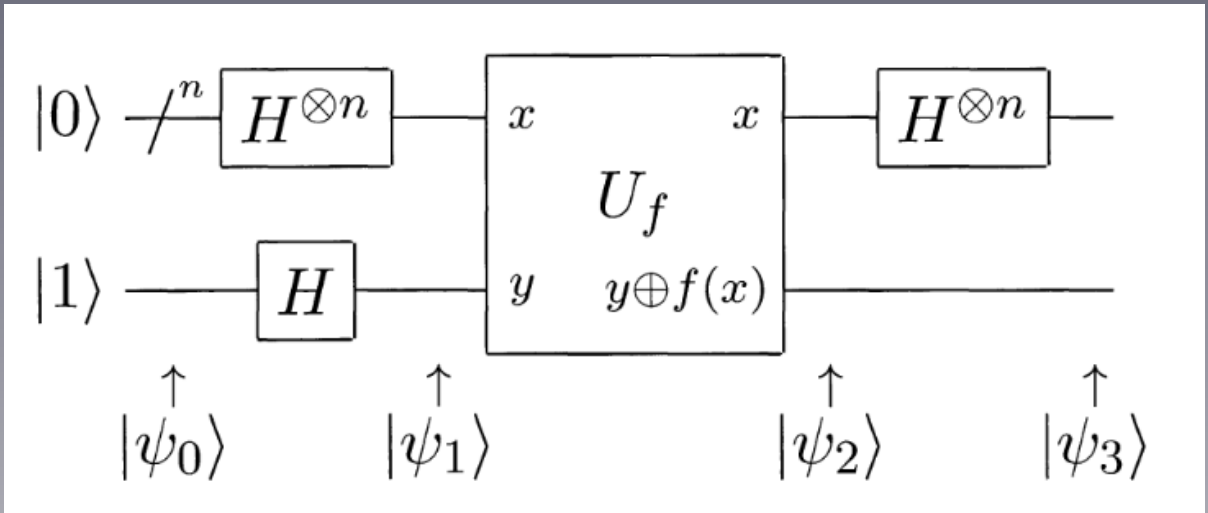
Deutsch-Josza




```
% balanced functions
% f(0,0)=1
% f(0,1)=0
% f(1,0)=0
% f(1,1)=1
Ufbl001   = [0 1 0 0 0 0 0 0;...
             1 0 0 0 0 0 0 0;...
             0 0 1 0 0 0 0 0;...
             0 0 0 1 0 0 0 0;...
             0 0 0 0 1 0 0 0;...
             0 0 0 0 0 1 0 0;...
             0 0 0 0 0 0 0 1;...
             0 0 0 0 0 0 1 0];
```

```
sz1 = psi3'*kron(kron(sigma_z,id),id)*psi3

sz1 =

   -1.0000

sz2 = psi3'*kron(kron(id,sigma_z),id)*psi3

sz2 =

   -1.0000
```

Deutsch-Josza




```
% f(0,0)=1
% f(0,1)=1
% f(1,0)=0
% f(1,1)=1 Note: this function is neither balanced nor constant
Ufb1101  = [0 1 0 0 0 0 0 0;...
            1 0 0 0 0 0 0 0;...
            0 0 0 1 0 0 0 0;...
            0 0 1 0 0 0 0 0;...
            0 0 0 0 1 0 0 0;...
            0 0 0 0 0 1 0 0;...
            0 0 0 0 0 0 0 1;...
            0 0 0 0 0 0 1 0];
```

```
sz1 = psi3'*kron(kron(sigma_z,id),id)*psi3

sz1 =

  -8.3267e-17

sz2 = psi3'*kron(kron(id,sigma_z),id)*psi3

sz2 =

   5.5511e-17
```

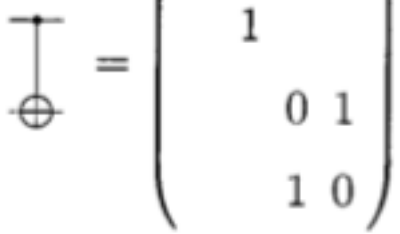
Quantum Gates

PHYSICAL REVIEW A **67**, 032301 (2003)

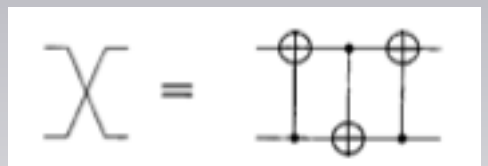
Natural two-qubit gate for quantum computation using the *XY* interaction

Norbert Schuch* and Jens Siewert†
Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany
(Received 30 July 2002; published 10 March 2003)

CNOT (controlled not) and single qubit rotations are universal



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



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

SWAP is not universal
can not create entanglement

Quantum Gates

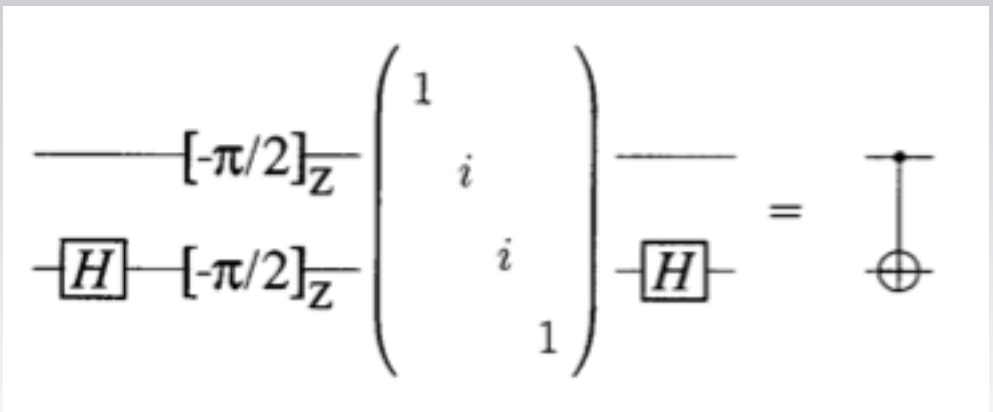
Unitary Evolution

$$U = \exp(-iHt/\hbar)$$

$$H = E^{ZZ}\sigma_z^{(1)} \otimes \sigma_z^{(2)}$$

Ising interaction

$$\exp\left[-i\mathcal{H}_{i,j}^{ZZ}(E_{i,j}^{ZZ})\frac{\pi}{E_{i,j}^{ZZ}}\right] = e^{i\pi/4}\begin{pmatrix} 1 & & & \\ & -i & & \\ & & -i & \\ & & & 1 \end{pmatrix}$$

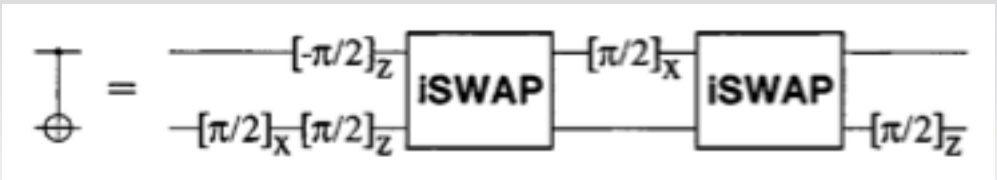


Quantum Gates

XY interaction

$$\mathcal{H}_{i,j}^{XY}(E_{i,j}^{XY}) = -\frac{E_{i,j}^{XY}}{4}[\sigma_x^{(i)}\sigma_x^{(j)} + \sigma_y^{(i)}\sigma_y^{(j)}].$$

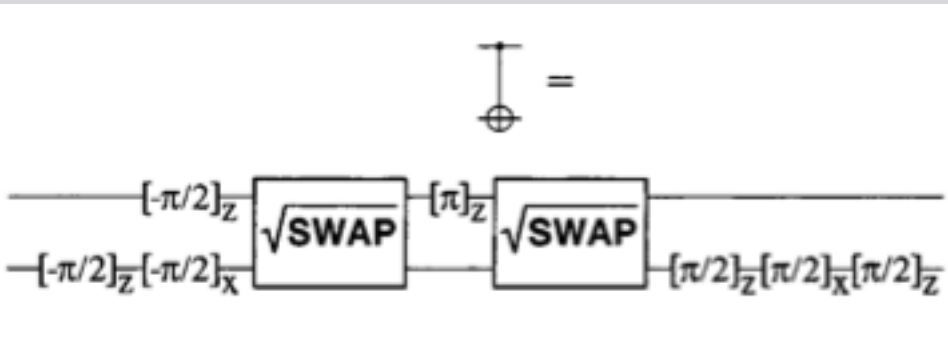
$$\text{iSWAP} := \begin{pmatrix} 1 & & & \\ & 0 & i & \\ & i & 0 & \\ & & & 1 \end{pmatrix} = \exp\left[-i\mathcal{H}_{i,j}^{XY}(E_{i,j}^{XY})\frac{\pi}{E_{i,j}^{XY}}\right].$$



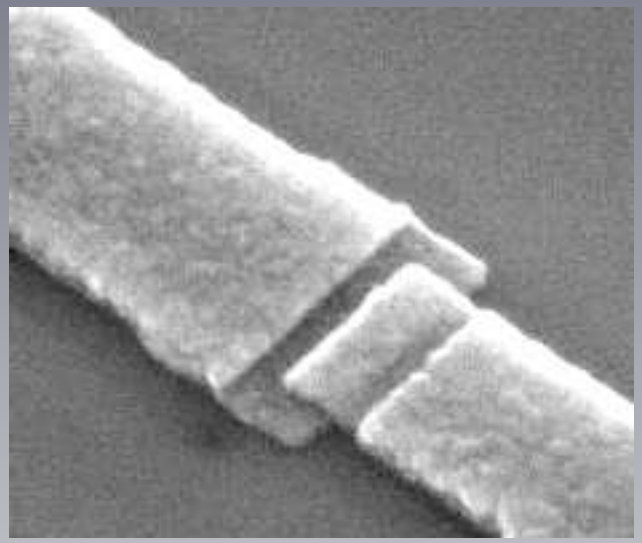
Heisenberg interaction

$$\mathcal{H}_{i,j}^{JJ}(E_{i,j}^{JJ}) = -\frac{E_{i,j}^{JJ}}{4}[\sigma_x^{(i)}\sigma_x^{(j)} + \sigma_y^{(i)}\sigma_y^{(j)} + \sigma_z^{(i)}\sigma_z^{(j)}],$$

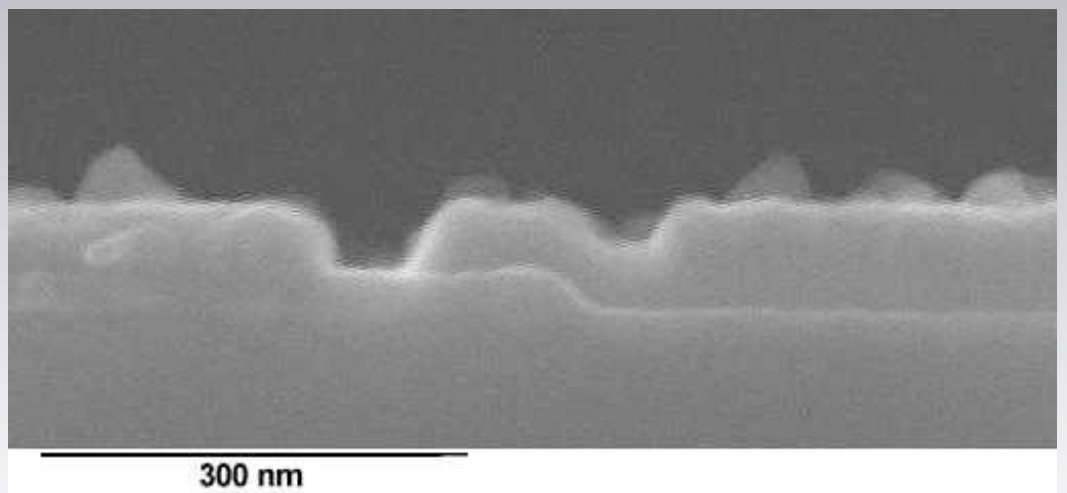
$$\exp\left[-i\mathcal{H}^{\mathcal{J}\mathcal{J}}\frac{\pi}{2E^{JJ}}\right] = e^{i\pi/8}\begin{pmatrix} 1 & & & \\ & \frac{1+i}{2} & \frac{1-i}{2} & \\ & \frac{1-i}{2} & \frac{1+i}{2} & \\ & & & 1 \end{pmatrix}$$



Josephson junction



$$I = I_0 \sin(\delta)$$



$$V = \frac{\phi_0}{2\pi}\dot{\delta} = \frac{\hbar}{2e}\dot{\delta}$$

tilted washboard potential