Physics of switches II

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The Physics of realistic switches

The previous analysis, although correct, is quite naïve, indeed.
The reason is that we have assumed that the work performed can be made arbitrarily small.

IS THIS TRUE?
In a macroscopic physical system, we have:

$\Delta U = L - Q$ Total energy variation during the switch

$\Delta U = 0$ → $L = Q$ and L=0

What about Q ?

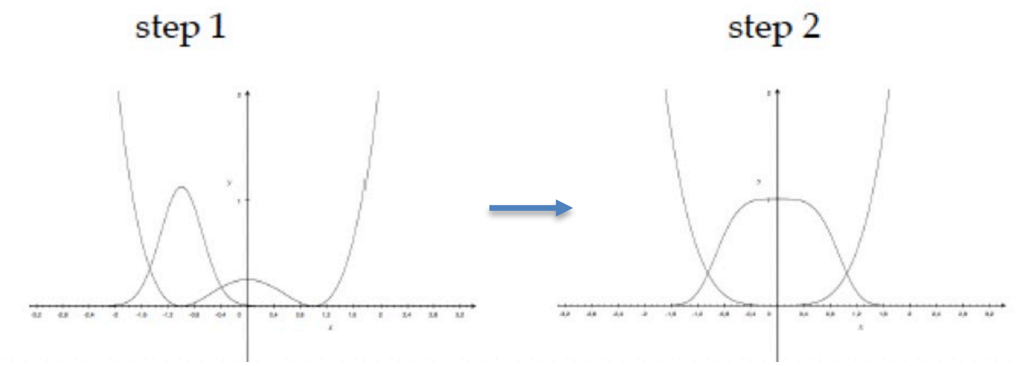
The second principle of thermodynamics requires that: $Q \geq T\Delta S$

$$Q = T\,\Delta S + friction$$

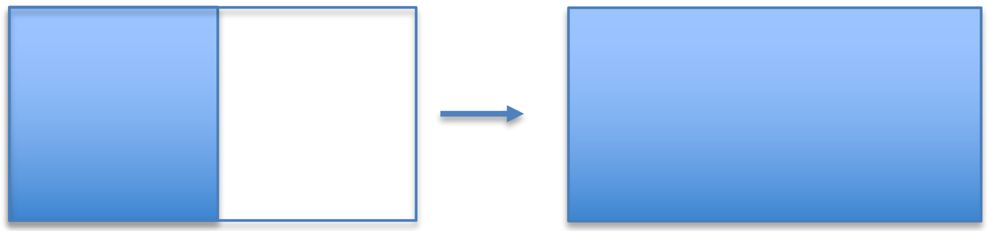
We might be able to make friction = 0 but…what about entropy?

The Physics of realistic switches

Rem: Free expansion is an irreversible operation

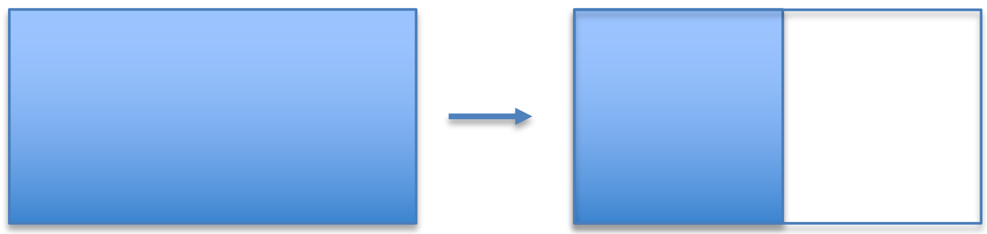


During free expansion the volume doubles



$$Q = 0$$

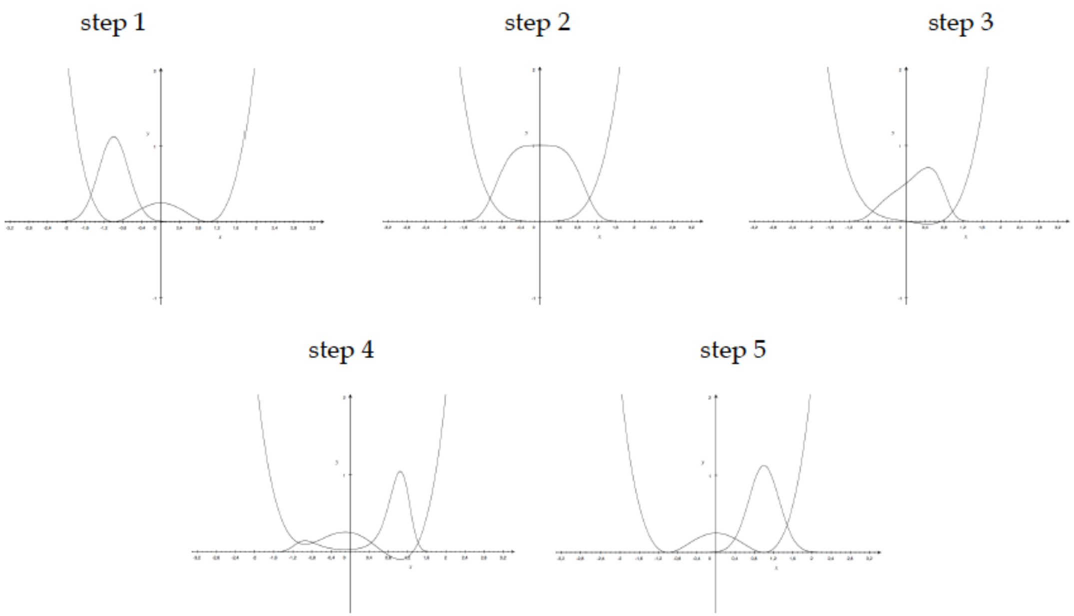
During compression the volume halves



$$Q = - T \Delta S = - K_B T \ln(2)$$

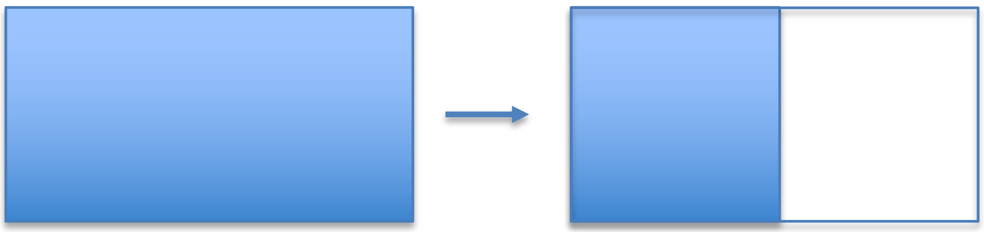
The Physics of realistic switches

Rem: Free expansion is an irreversible operation



During compression the volume halves

$$Q = - T \Delta S = -2 K_B T$$



The Physics of realistic switches

Based on these considerations we can now reformulate conditions required in order to perform the switch by spending zero energy:

1) The total work performed on the system by the external force has to be zero.
2) The switch event has to proceed with a speed arbitrarily small in order to have arbitrarily small losses due to friction.
3) The system entropy **never decreases** during the switch event **or** the increase-decrease is performed at equilibrium (no free expansion).

Is it possible?

A protocol for switch at constant entropy

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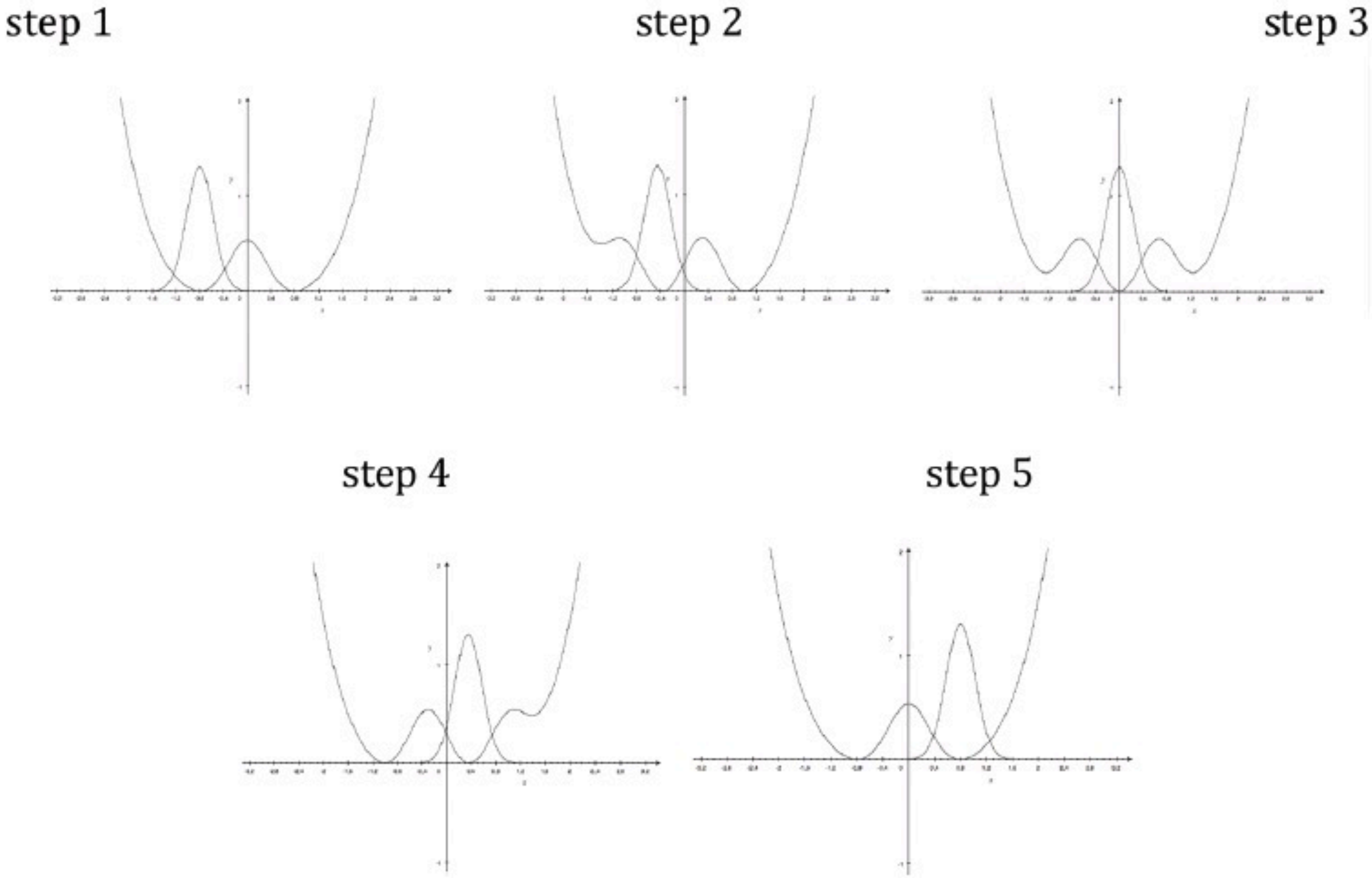
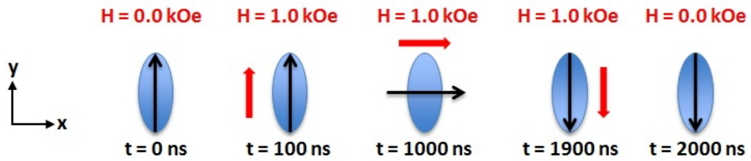
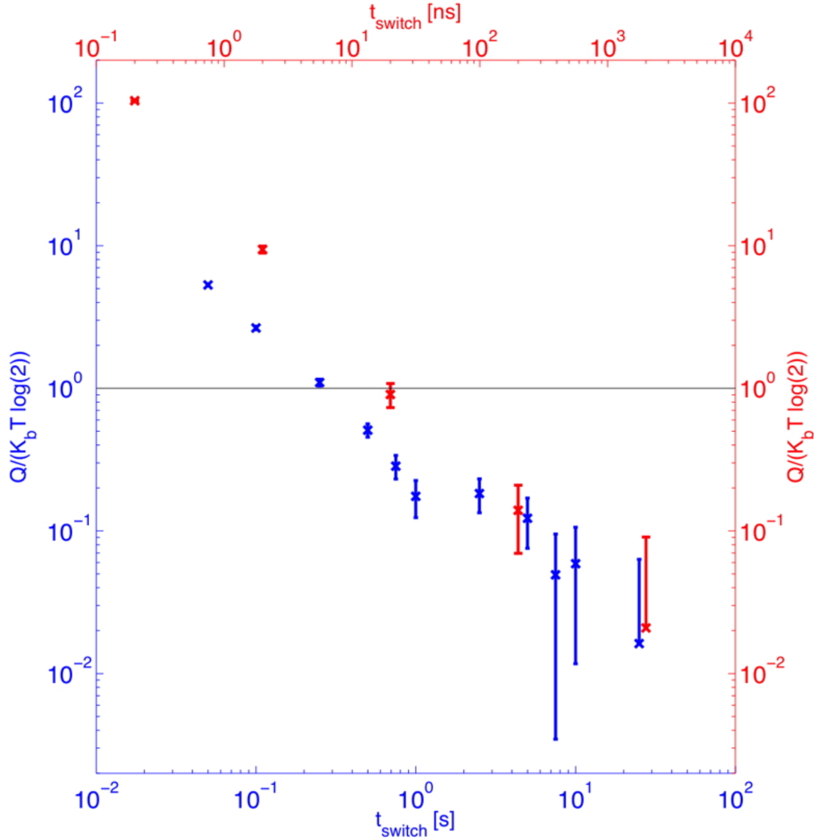
The Physics of realistic switches

Here is a possible scheme where we show a switch event where the system entropy **never decreases** during the switch event.





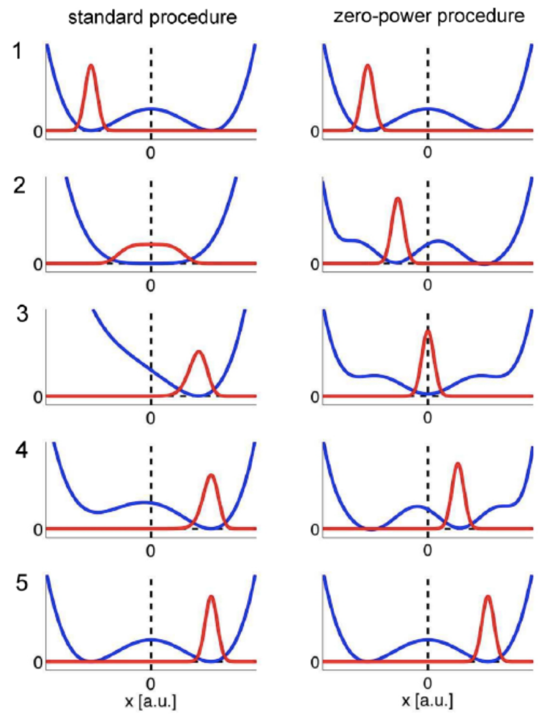


Magnetic nano dots

Single cylindrical element of permalloy (NiFe) with dimensions 50 x 50 x 5 nm³

Entropy changes

Entropy stays constant



More info available at www.landauer-project.eu

The Physics of realistic switches: the switch

In conclusion we have shown that, at least in principle, if the switch event is realized according to the following rules:

1) The total work performed on the system by the external force has to be zero.
2) The switch event has to proceed with a speed arbitrarily small in order to have arbitrarily small losses due to friction.
3) The system entropy **never decreases** during the switch event or the total change of the entropy is zero and the all process is realized through states of equilibrium.

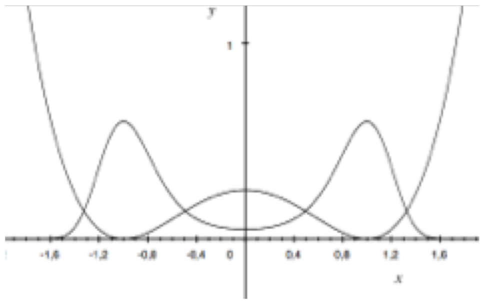
Then the switch event can be made by spending ZERO energy.
What we have seen for sequential switches applies to combinatory switches as well.

Thus we can say that the computing activity, which is made by assembling switch events, can be made entirely by spending zero energy.

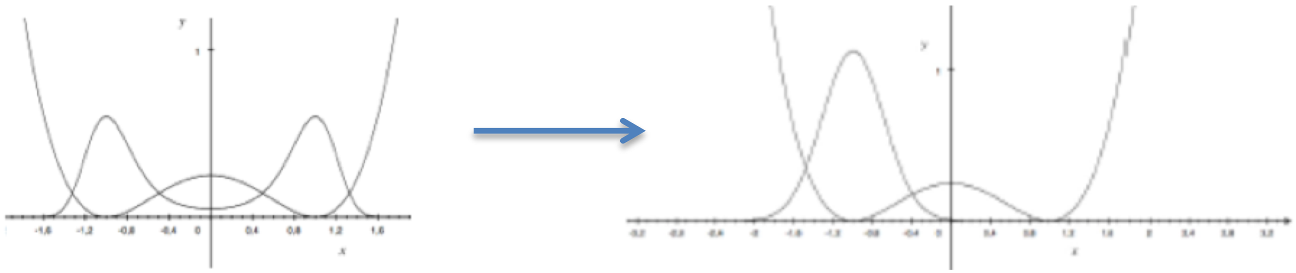
There is an exception for what concerns the memory use.

The Physics of realistic switches: the reset operation

But… let's suppose we start from an equilibrium condition



In this case if we want to write a memory bit or to use the switch we need to operate a **reset operation**



Is there a minimal cost for this operation?

THE LANDAUER LIMIT

The Landauer's principle states that erasing one bit of information (like in a resetting operation) comes unavoidably with a decrease in physical entropy and thus is accompanied by a minimal dissipation of energy equal to

$$Q = k_B \, T \ln 2$$

More technically this is the result of a change in entropy due to a change from a random state to a defined state.

Please note: this is the **minimum** energy required.

At room temperature $Q = 1.38 \; 10^{-23} \quad 300 \quad 0.69 \quad = 2{,}86 \; 10^{-21}$ J

About $3 \; 10^{-21}$ Joule

In conclusion

In conclusion we have shown that, at least in principle,

1) The switch event can be made by spending ZERO energy.

2) The reset event requires a minimum expenditure of energy. $Q = K_B T \ln(2)$

To know more

- Review article: Towards zero-power ICT, L Gammaitoni, D Chiuchiú, M Madami, G Carlotti Nanotechnology 26 (22), 222001 (2015)

- Book: *ICT - Energy - Concepts Towards Zero - Power Information and Communication Technology*, InTech, February 2, 2014.