Design of electroactive bacteria by coupling genetic networks to redox environments

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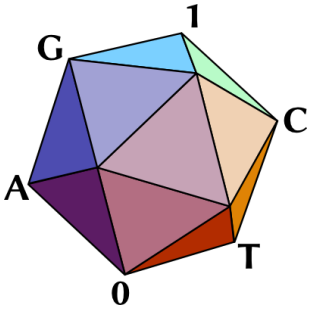
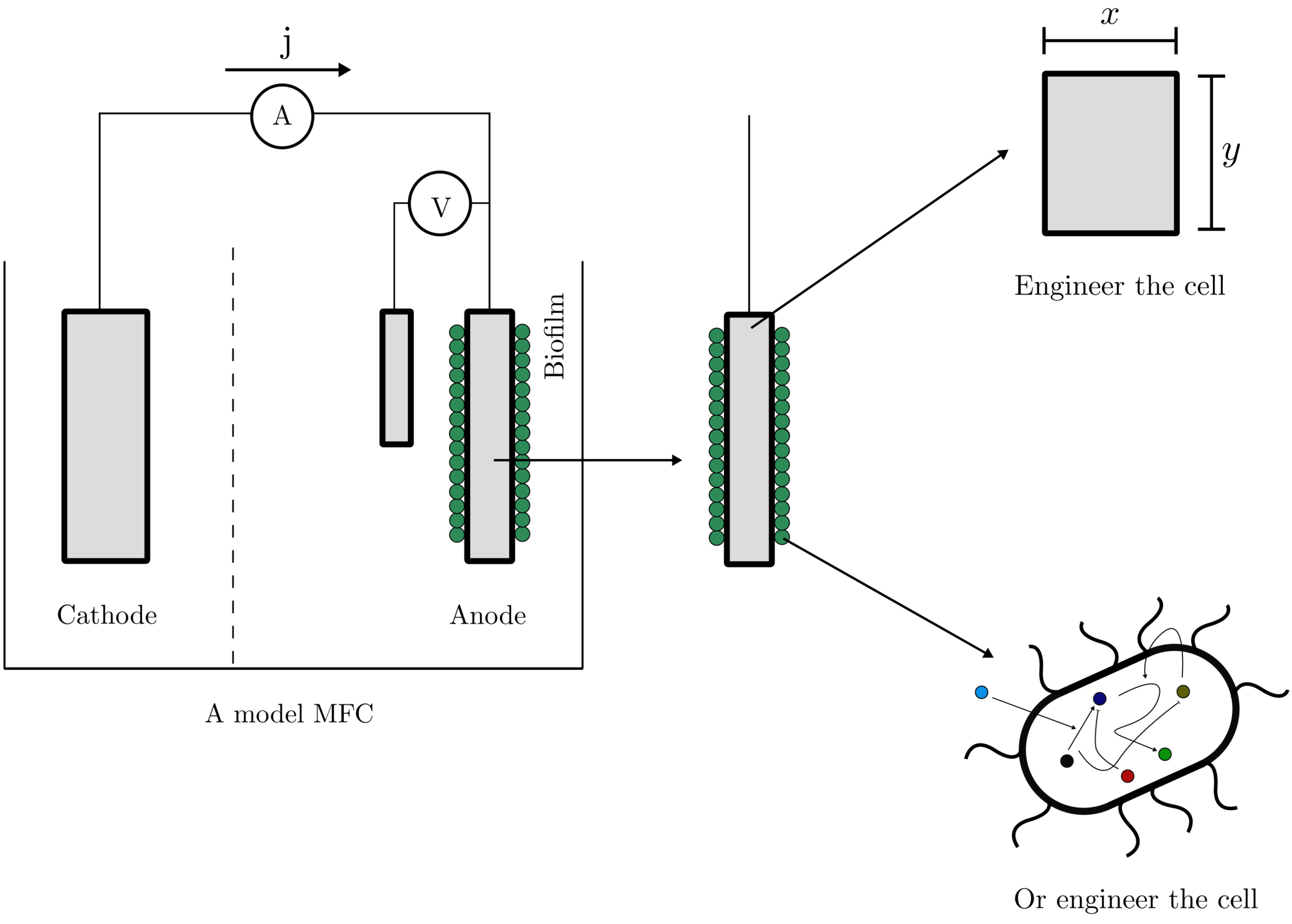
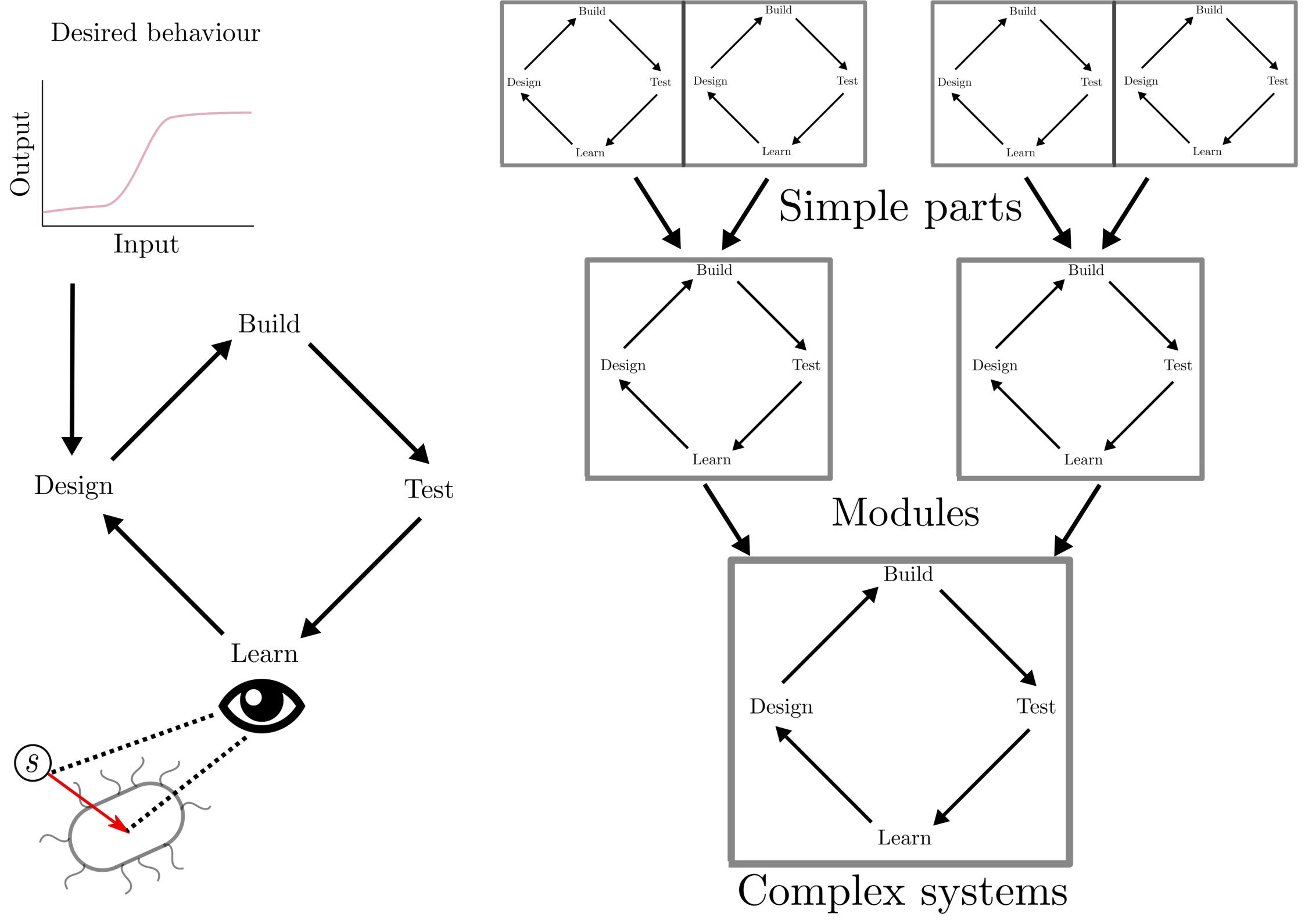
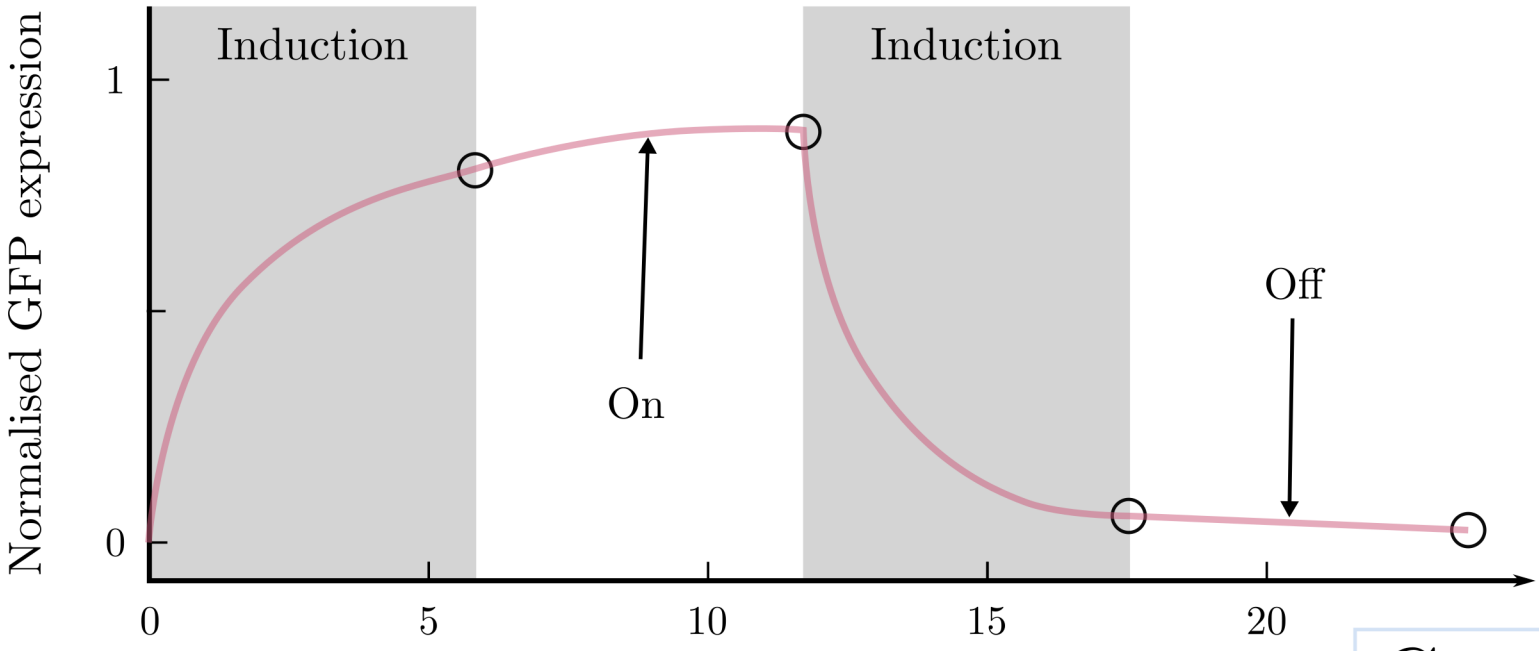


ICOS Group


j
A
V
Biofilm
Cathode
Anode
A model MFC
x
y
Engineer the cell
Or engineer the cell


Desired behaviour
Output
Input
Build
Design
Test
Learn
S
Simple parts
Modules
Complex systems



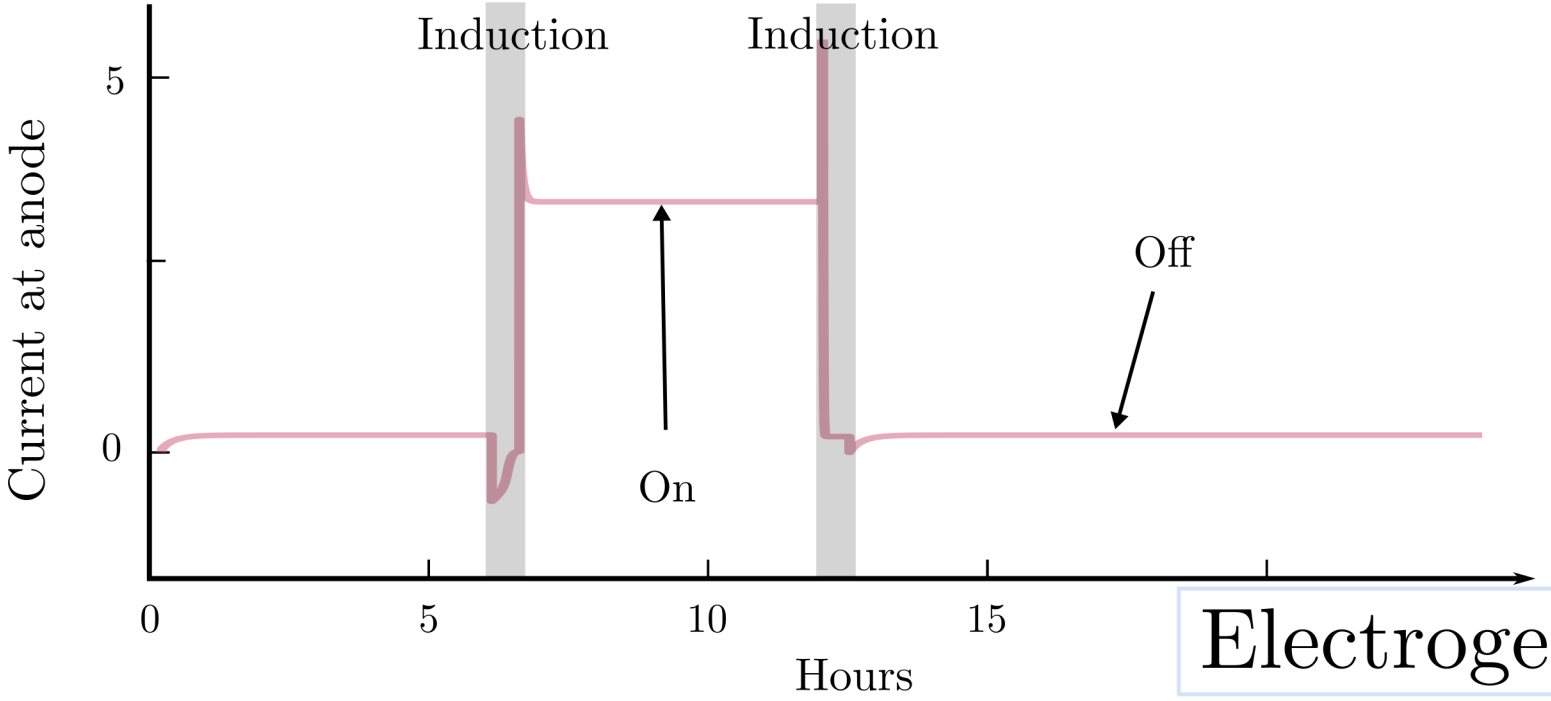
High expression

Chemical induction

Low expression

Adapted from Gardner, T., Cantor, C. and Collins, J. Construction of a genetic toggle switch in Escherichia coli. Nature 2000

Genetic toggle switch

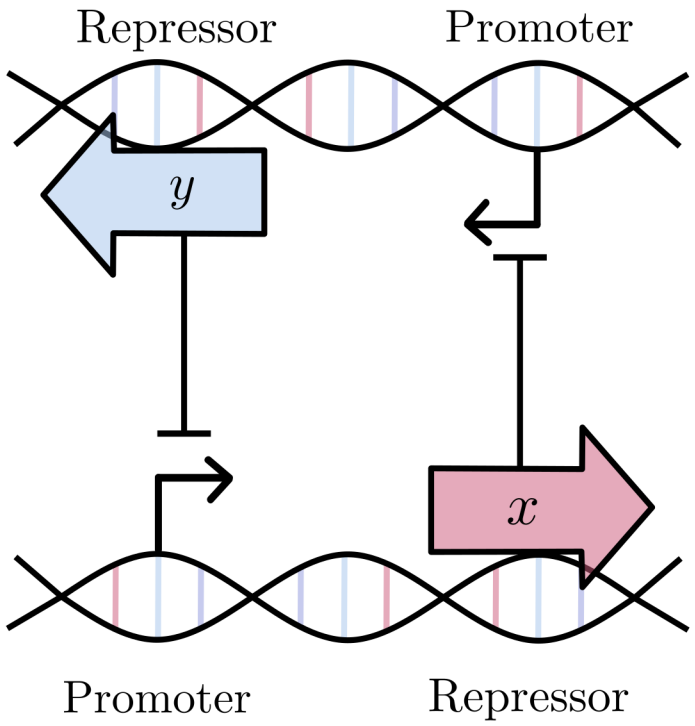


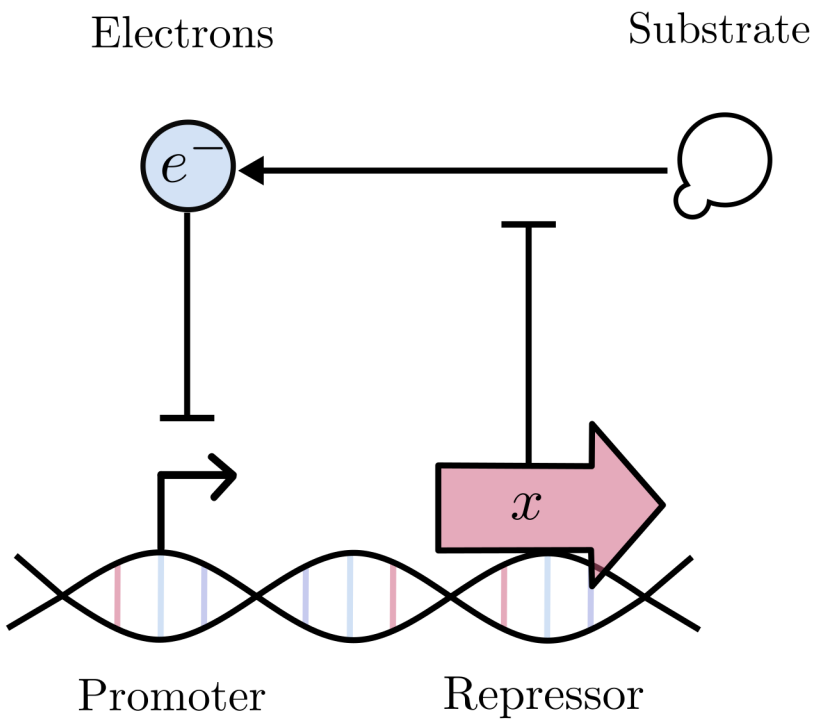
High current

Electronic induction

Low current

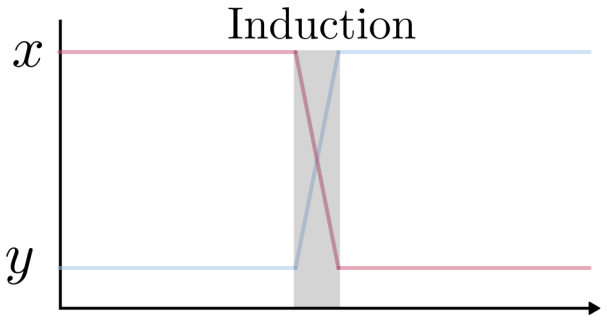
Electrogenic toggle switch

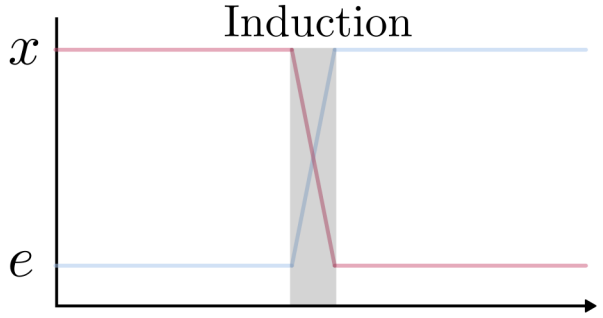


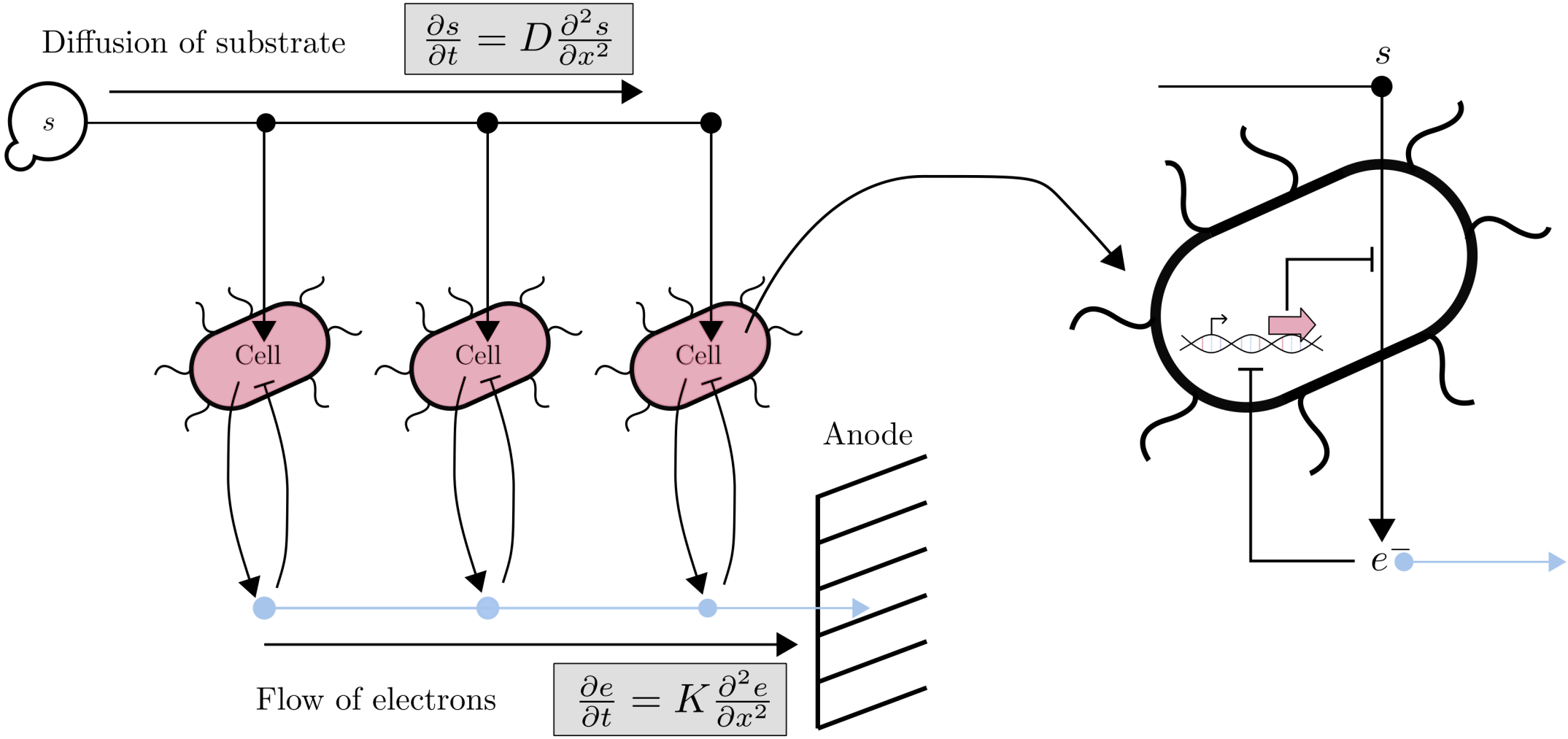


- Two genetic components
- Each gene inhibits the other
- Either x or y is highly expressed

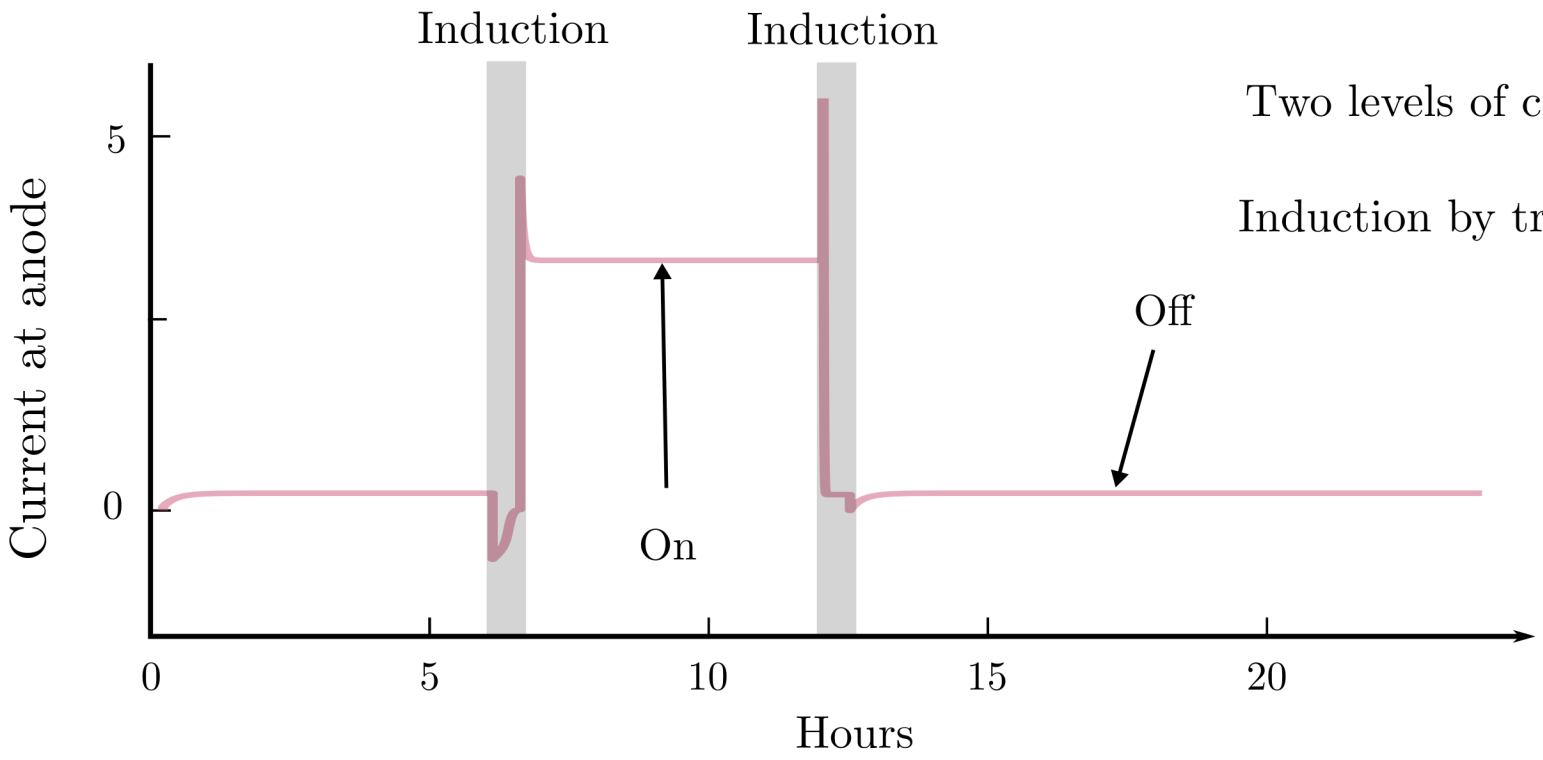
- One genetic one electrogenic component
- x inhibits electron 'production', electrons inhibit x
- Either lots of electrons, or lots of x





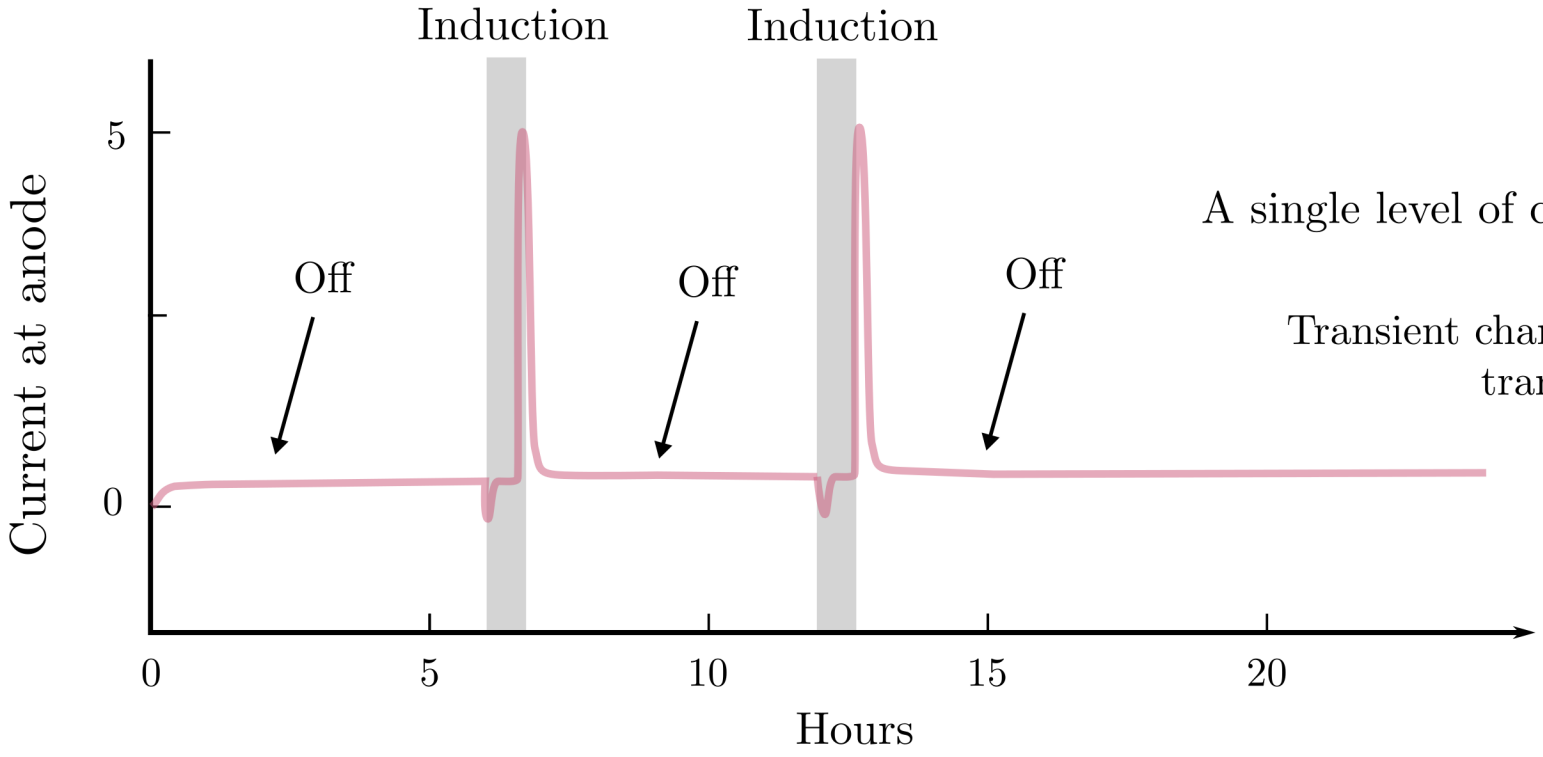


- One dimensional substrate diffusion modeled with PDE
- One dimensional electron flow modeled with PDE
- Cells communicate between substrate and electrons at different depths in biofilm
- Genetic component modeling with ODE
- Cells consume substrate, produce electrons at a rate determined by internal state



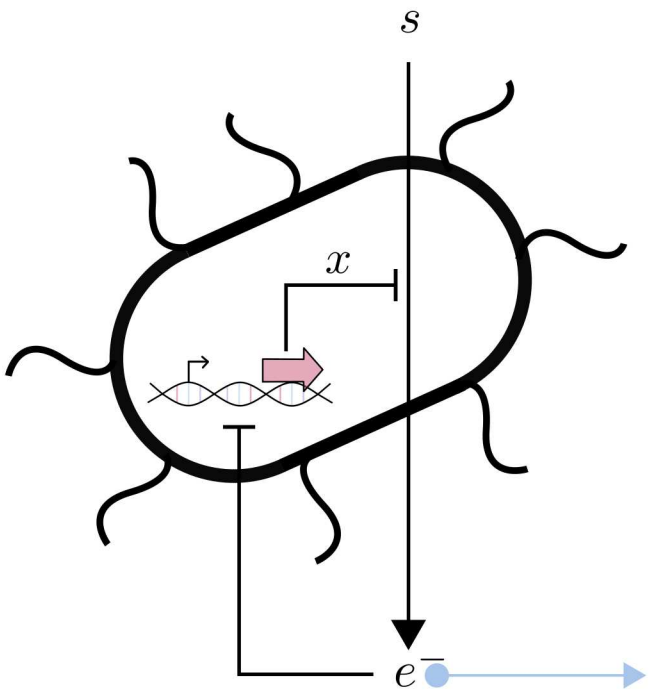
Two levels of current for a single overpotential

Induction by transient change in overpotential



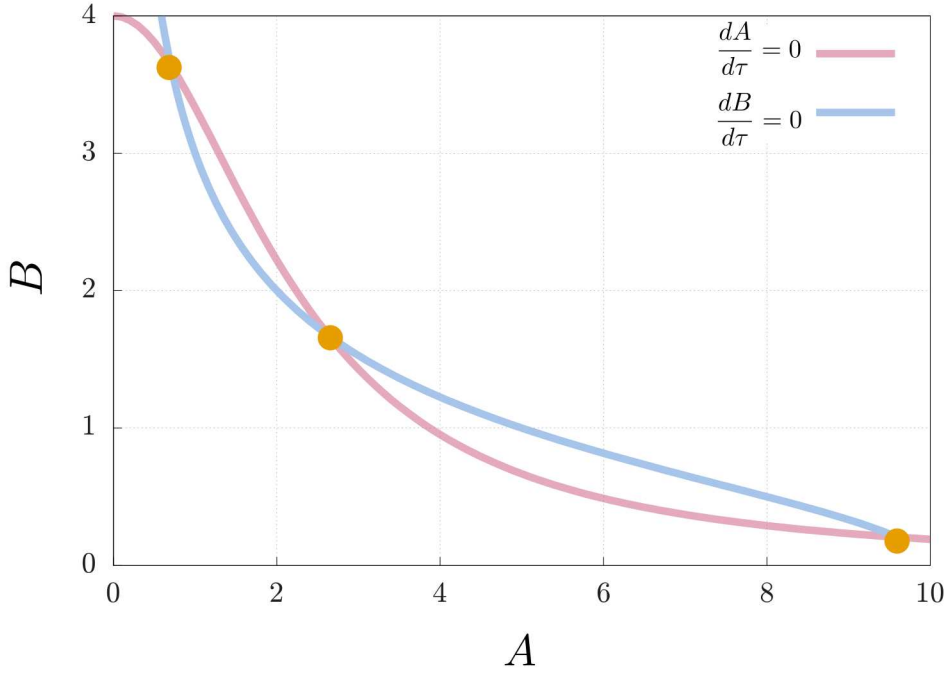
A single level of current for a single overpotential

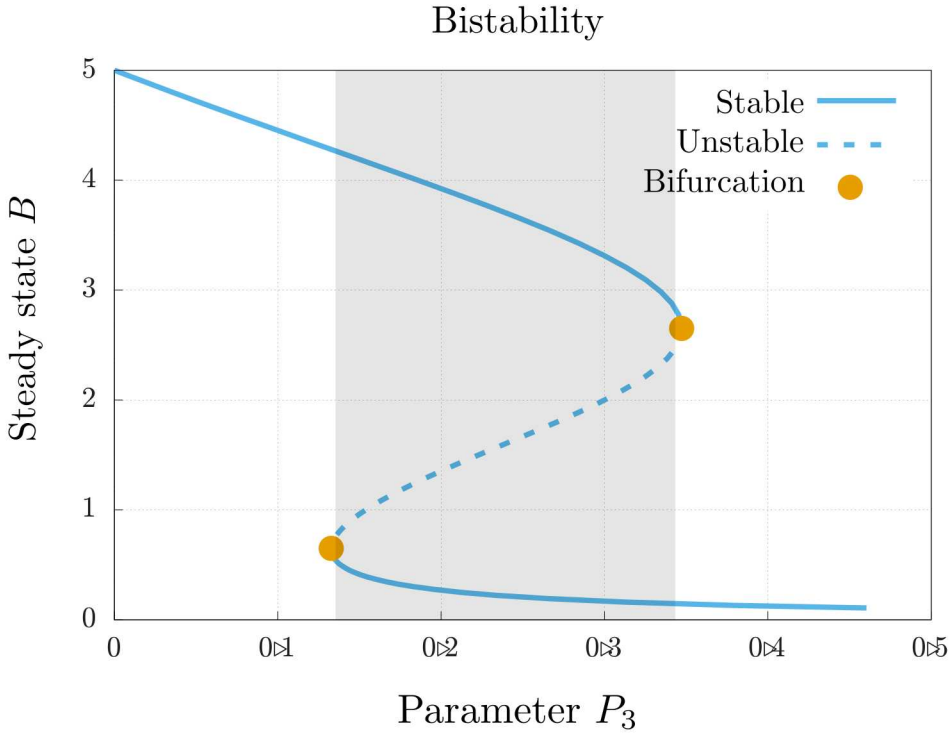
Transient change in overpotential produces only transient change in current

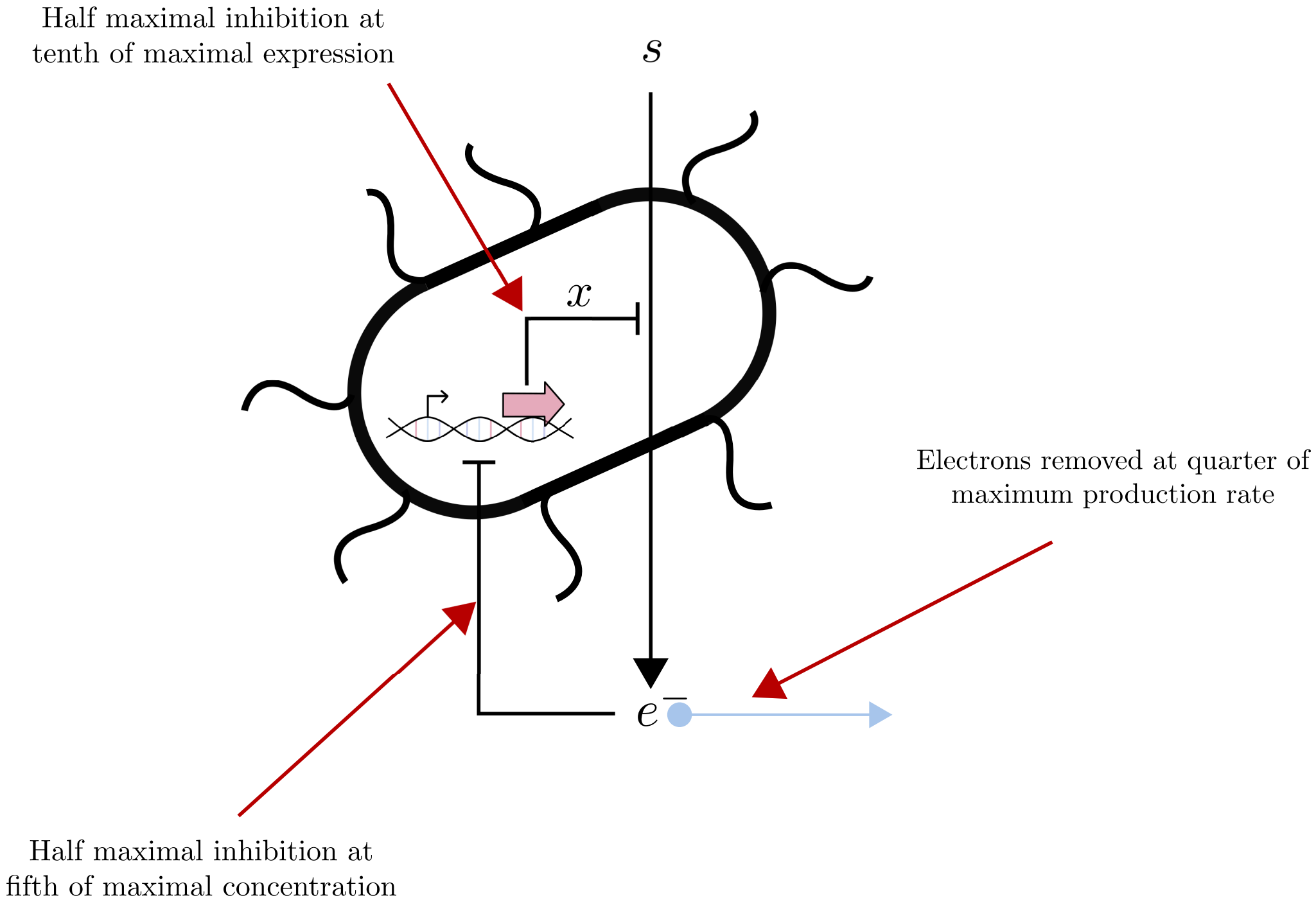


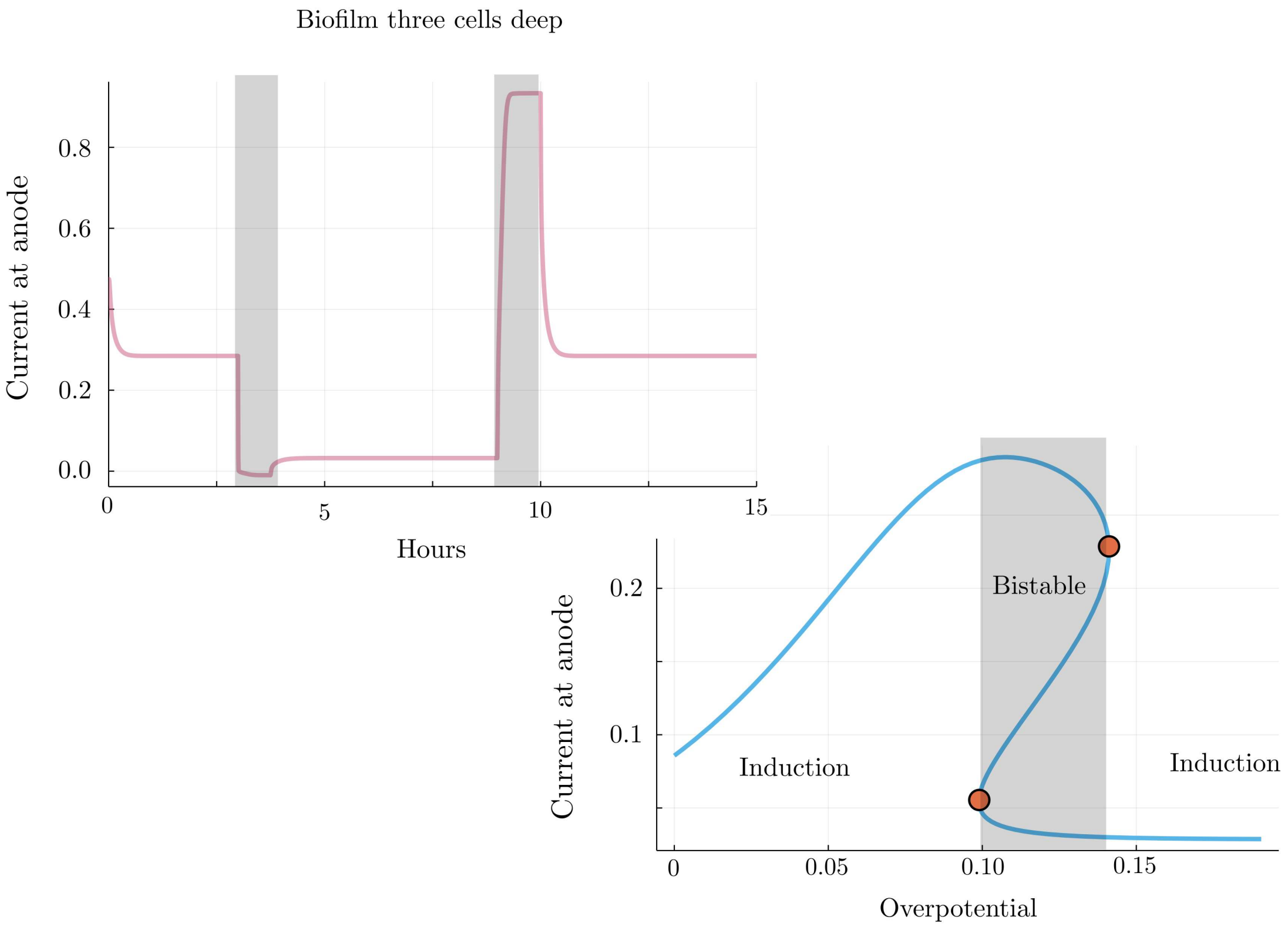
$$\frac{dA}{d\tau} = \frac{P_1}{1+B^2} - P_2 A$$

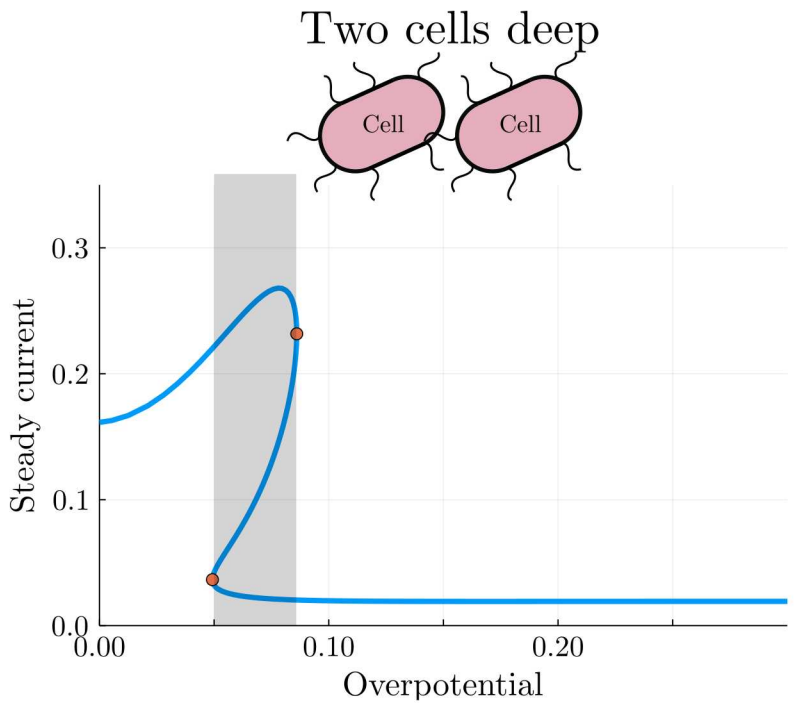
$$\frac{dB}{d\tau} = \frac{B_0 - B}{1+A^2} - P_3 B$$

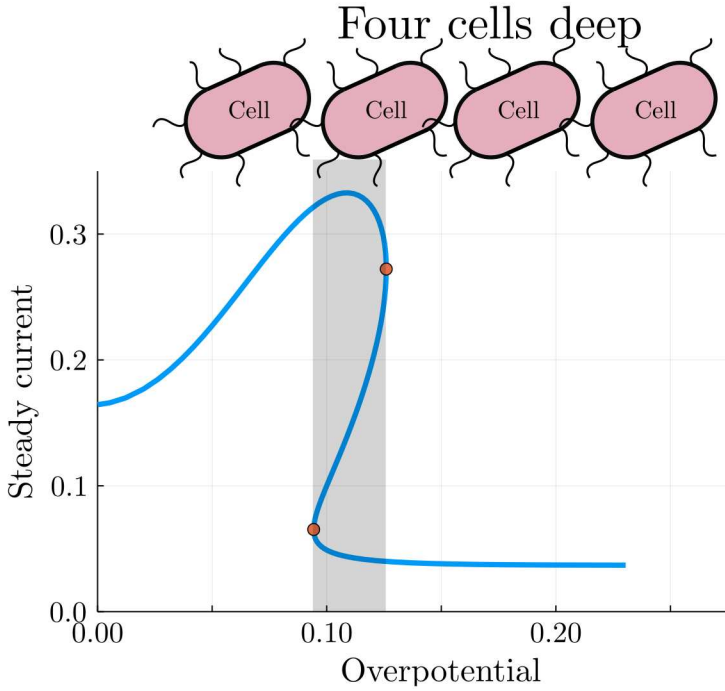


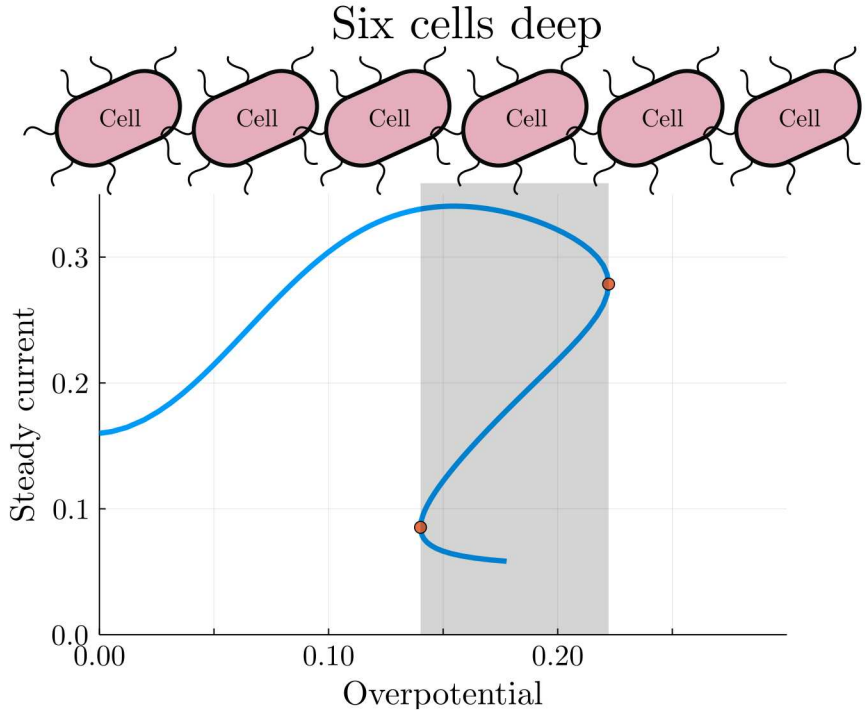


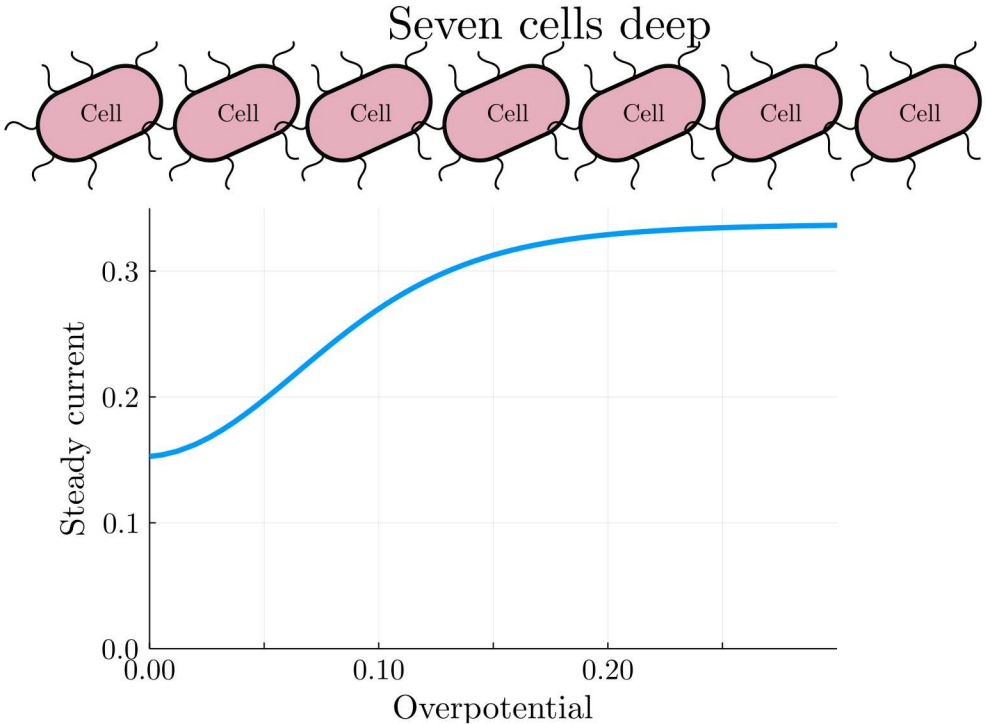

Half maximal inhibition at
tenth of maximal expression
s
x
Electrons removed at quarter of
maximum production rate
e^-
Half maximal inhibition at
fifth of maximal concentration

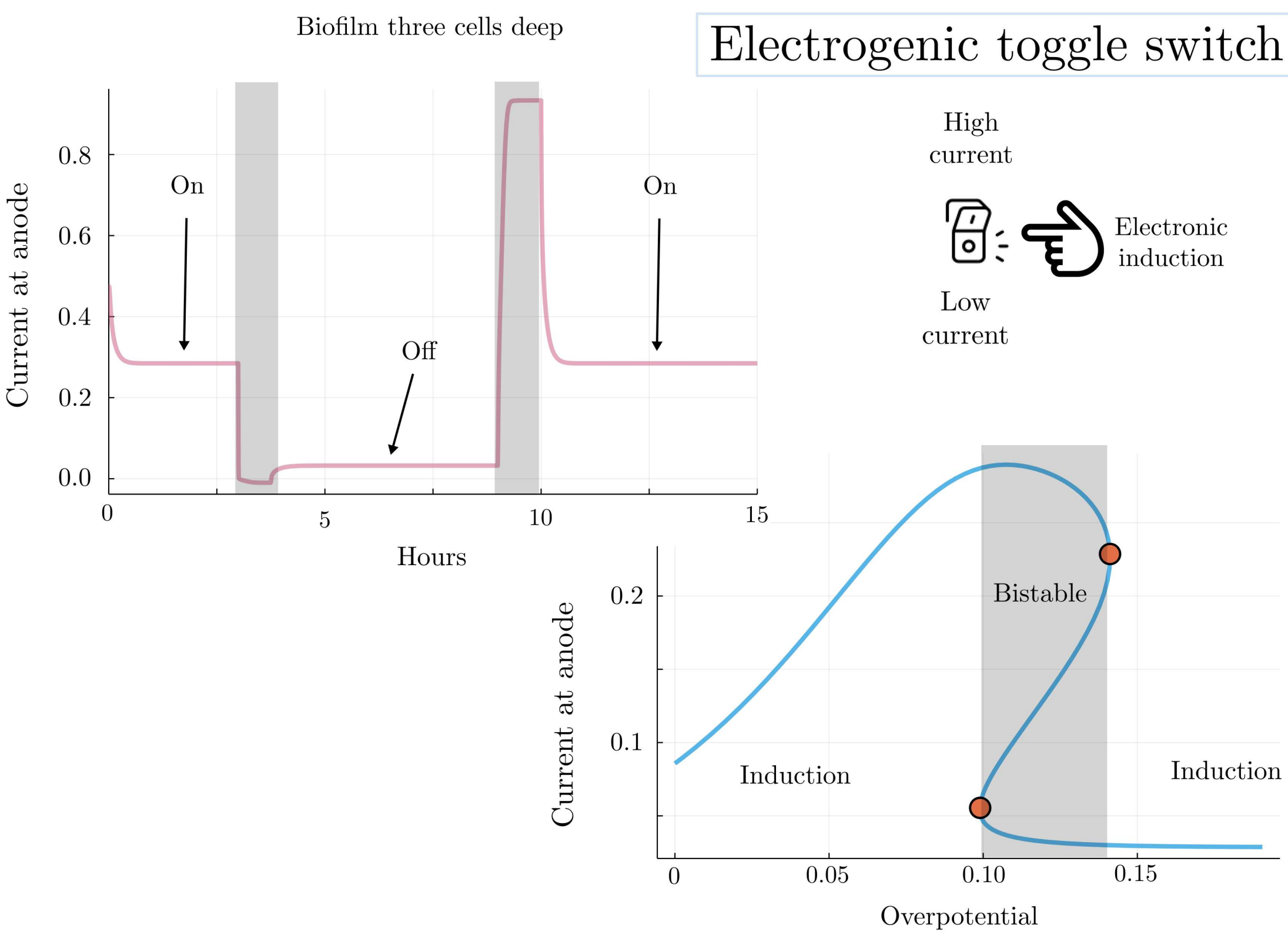

Biofilm three cells deep
Current at anode
0.0
0.2
0.4
0.6
0.8
0
5
10
15
Hours
Current at anode
0.1
0.2
Bistable
Induction
Induction
0
0.05
0.10
0.15
Overpotential


Two cells deep
Cell
Cell
Steady current
0.0
0.1
0.2
0.3
0.00
0.10
0.20
Overpotential


Four cells deep
Cell
Cell
Cell
Cell
Steady current
0.0
0.1
0.2
0.3
0.00
0.10
0.20
Overpotential


Six cells deep
Cell
Cell
Cell
Cell
Cell
Cell
Steady current
0.0
0.1
0.2
0.3
0.00
0.10
0.20
Overpotential


Seven cells deep
Cell
Cell
Cell
Cell
Cell
Cell
Cell
Steady current
0.0
0.1
0.2
0.3
0.00
0.10
0.20
Overpotential


Biofilm three cells deep
Current at anode
0.0
0.2
0.4
0.6
0.8
On
Off
On
0
5
10
15
Hours
Electrogenic toggle switch
High
current
Electronic
induction
Low
current
Current at anode
0.1
0.2
Bistable
Induction
Induction
0
0.05
0.10
0.15
Overpotential