Synchronization: an introduction

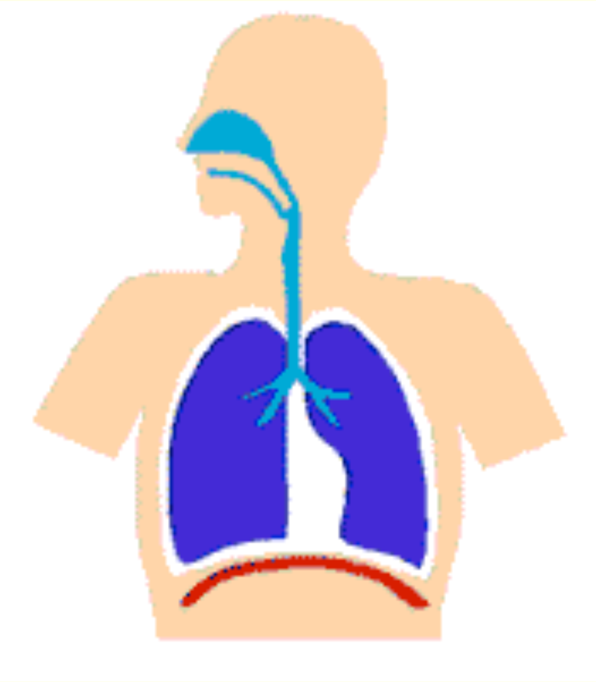
Michael Rosenblum

Institute of Physics and Astronomy, Potsdam University, Germany

URL: *www.stat.physik.uni-potsdam.de/~mros*

Synchronization: what is it about?

1 It is about **oscillatory objects**



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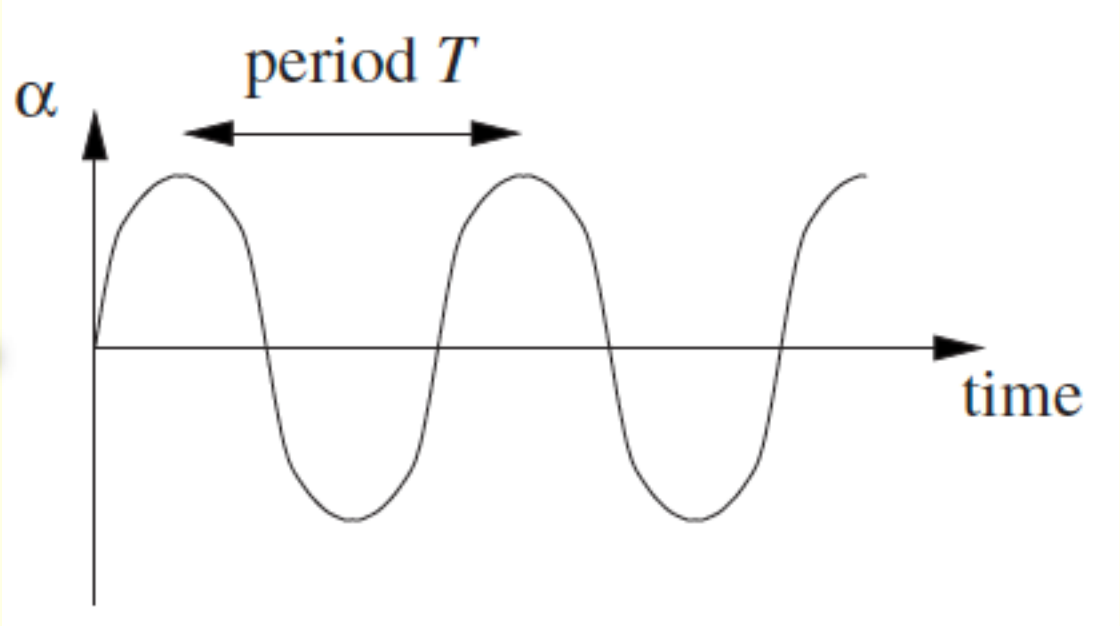

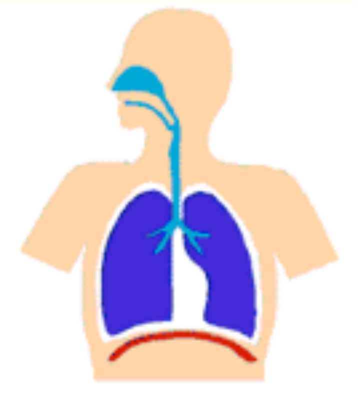

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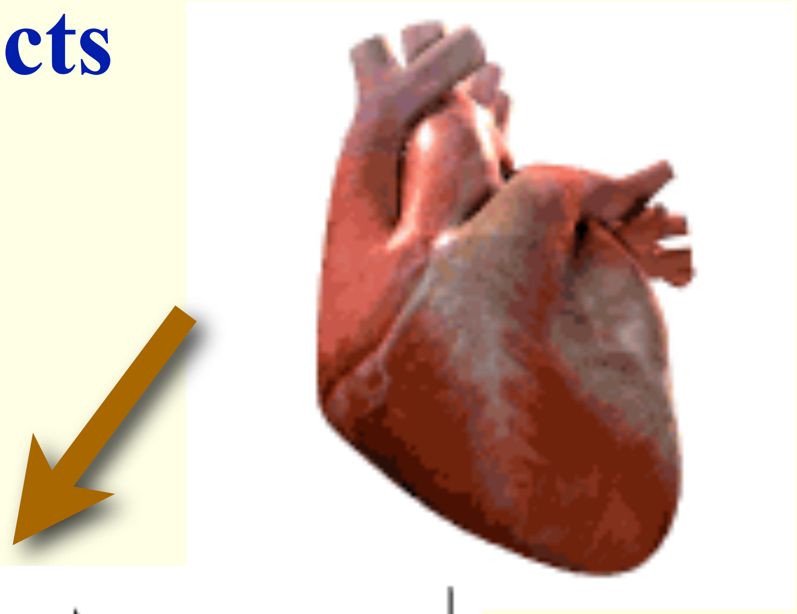

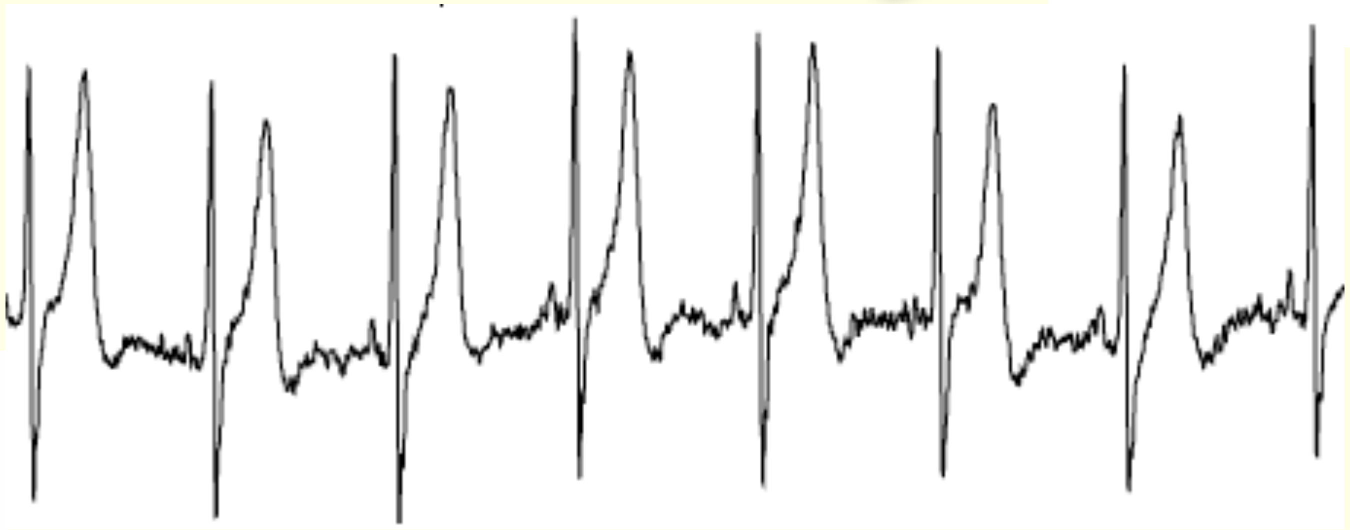

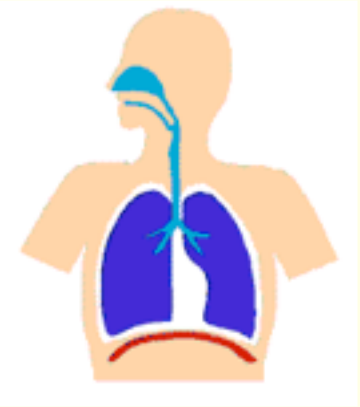

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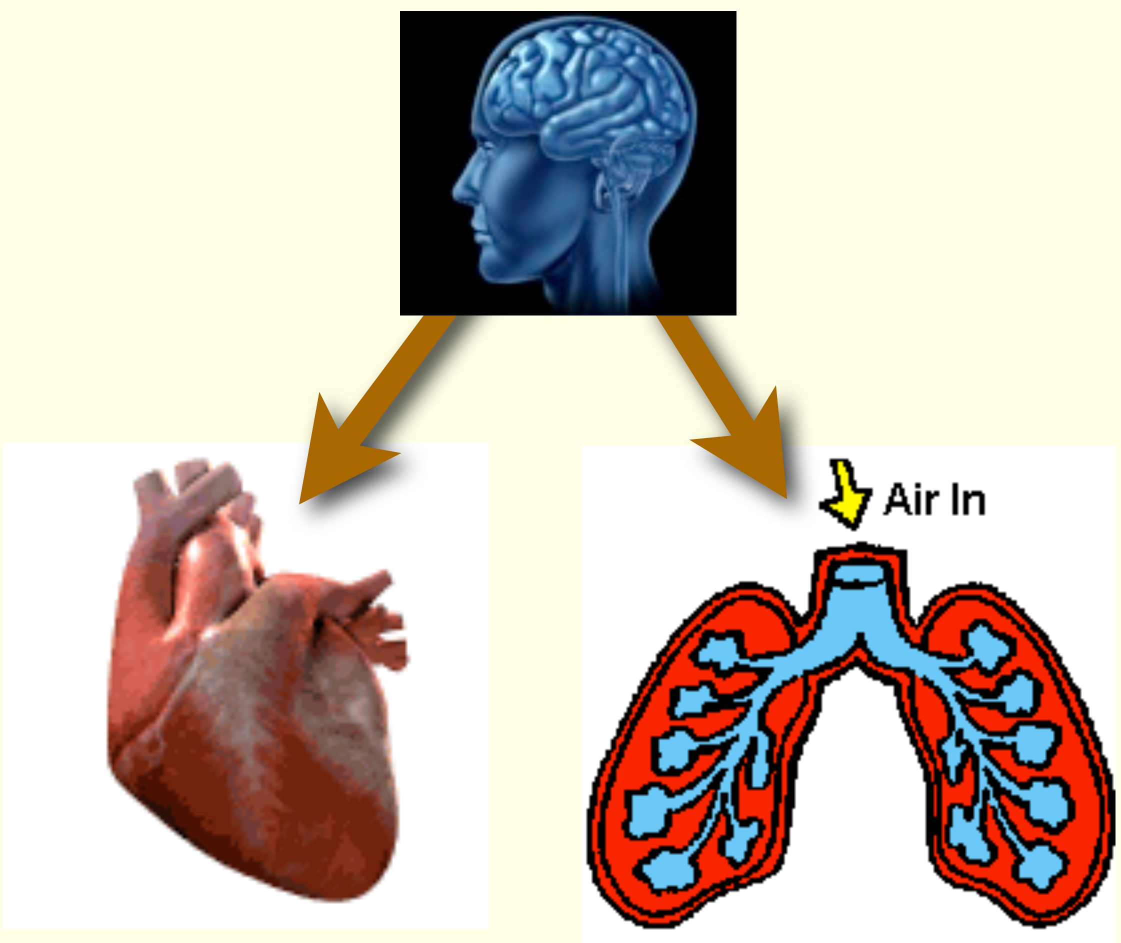
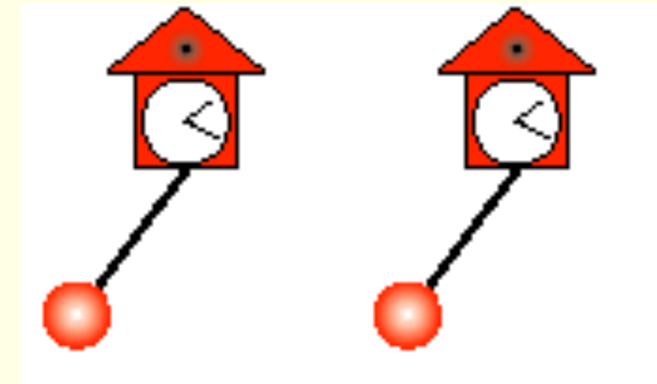
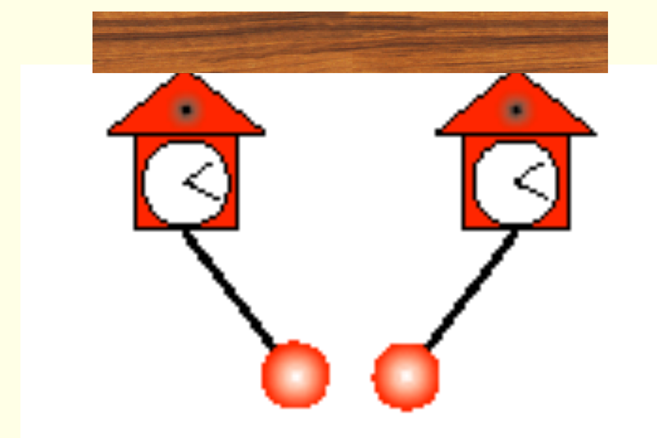
Synchronization: what is it about?

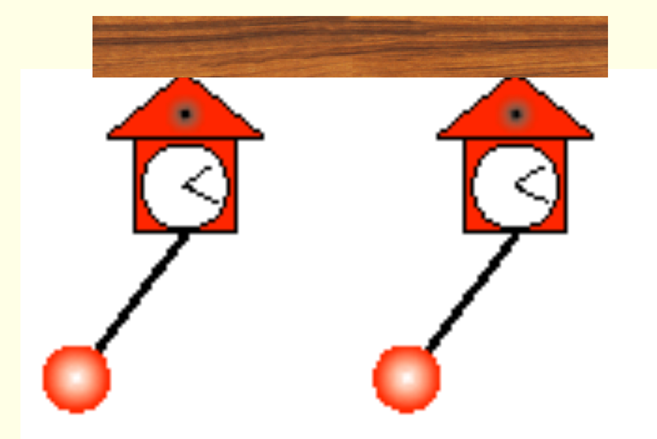
1 It is about **oscillatory objects**

2 Its about their **weak interaction**









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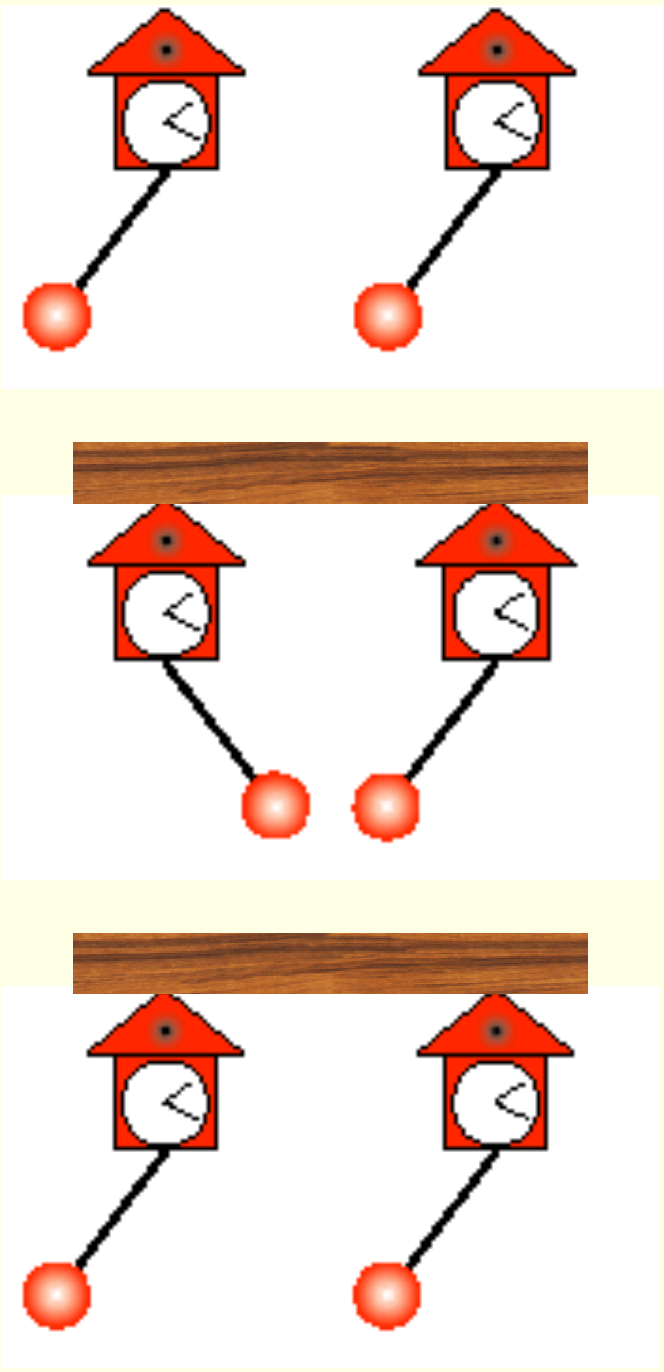
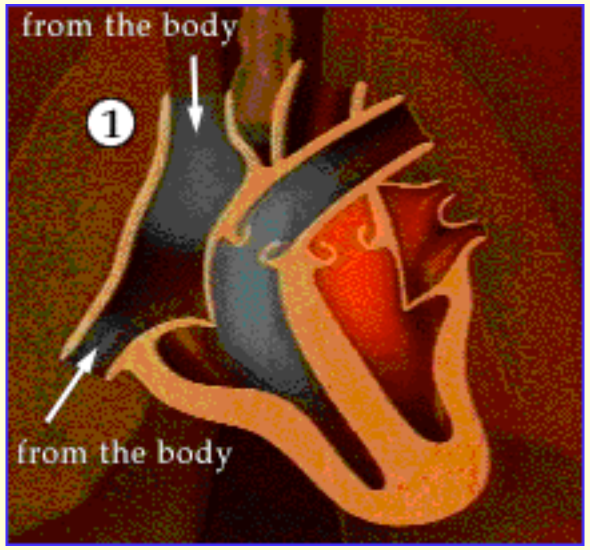


Synchronization is adjustment of rhythms of active (self-sustained) **oscillatory objects** due to their **weak interaction**

Self-sustained oscillators



Active oscillators

Biology: systems generating endogenous rhythms

Systems of this class:

1. generate stationary oscillations without periodic forces
2. are dissipative nonlinear systems
3. are described by autonomous differential equations
4. are represented by a limit cycle in the phase space

Synchronization is possible for self-sustained oscillators only!

Demonstration of synchronization I

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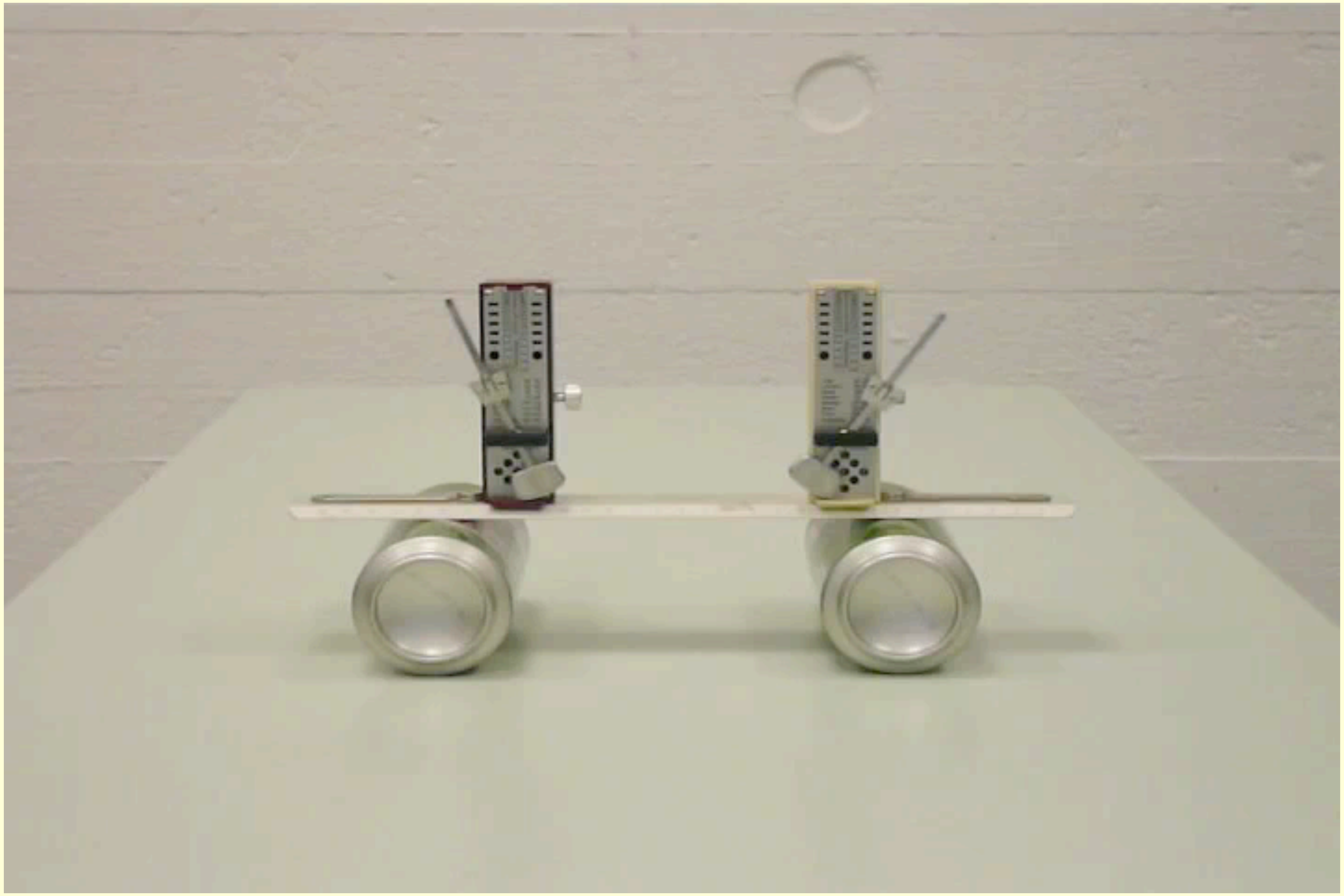

Demonstration of synchronization II

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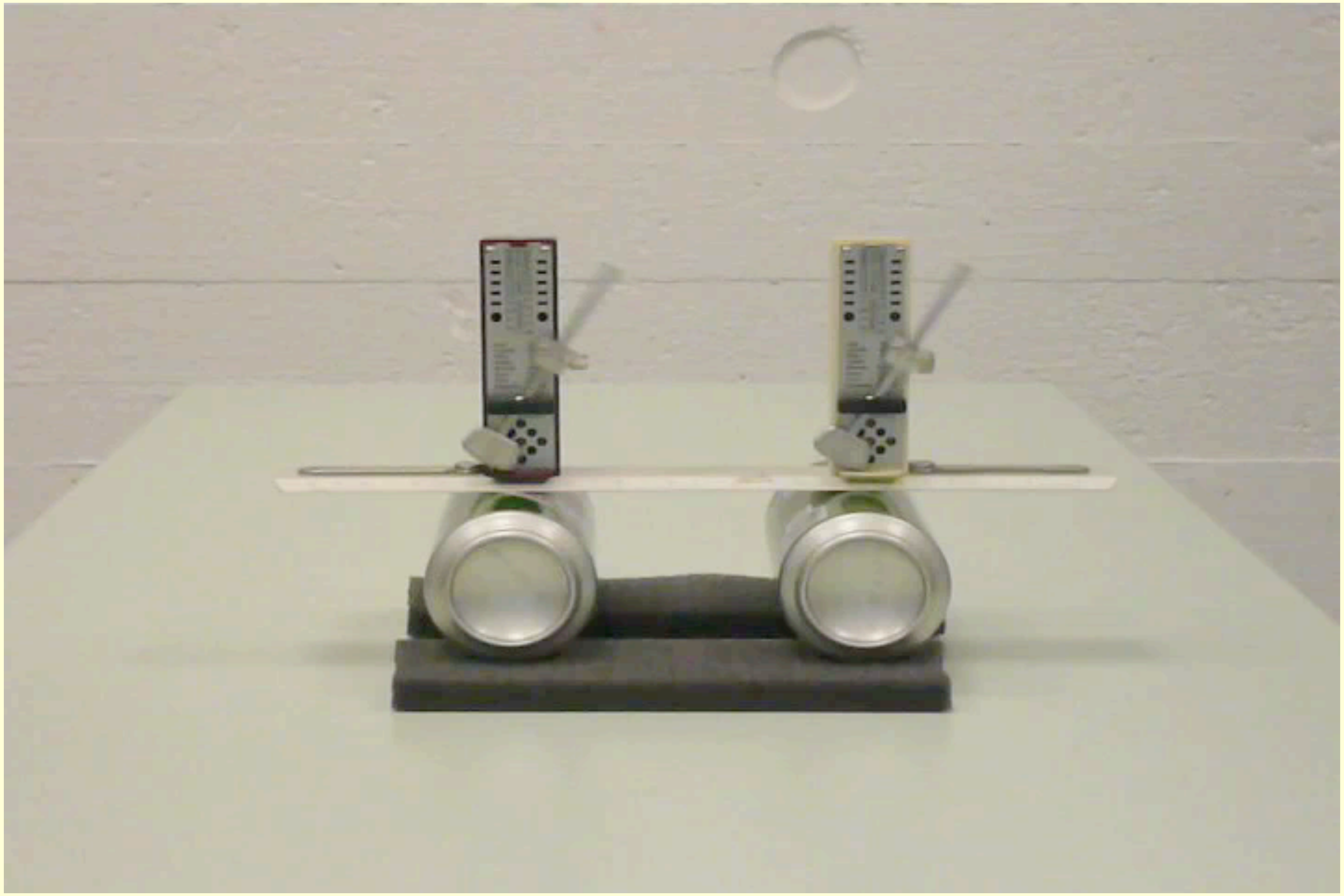
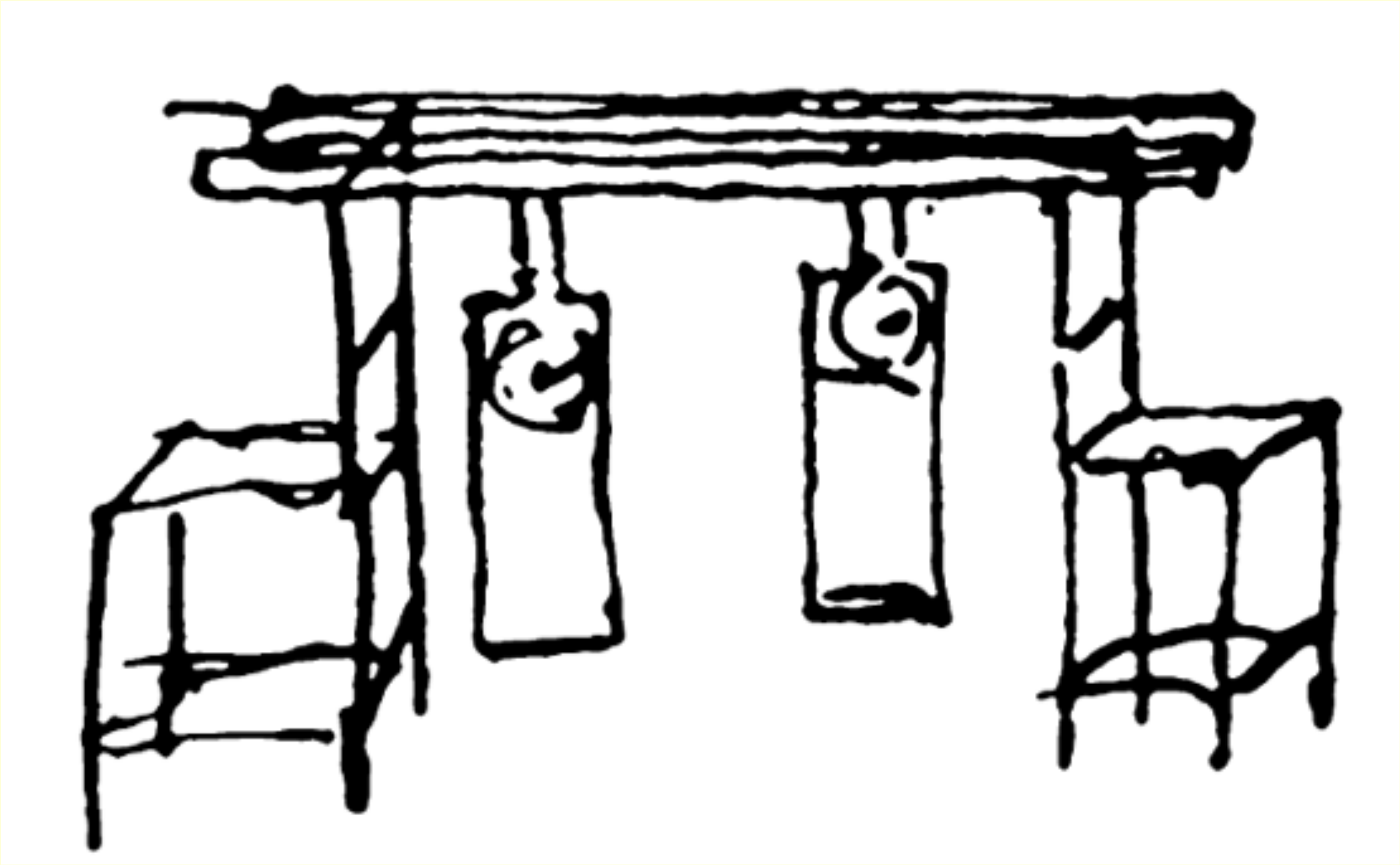
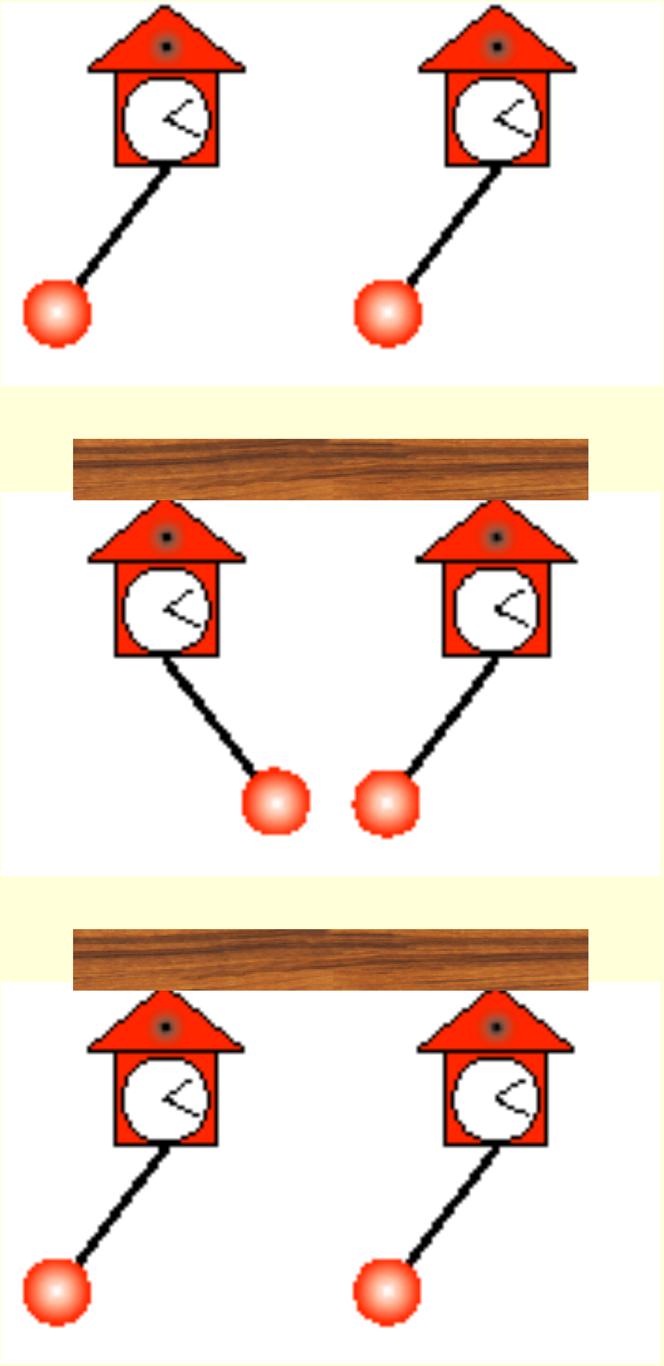


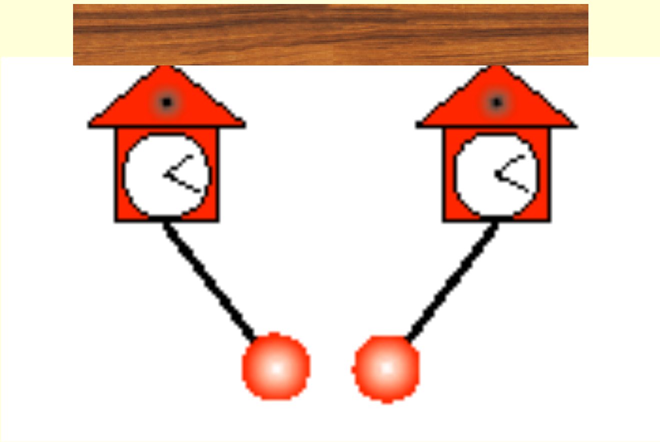
Discovery of synchronization

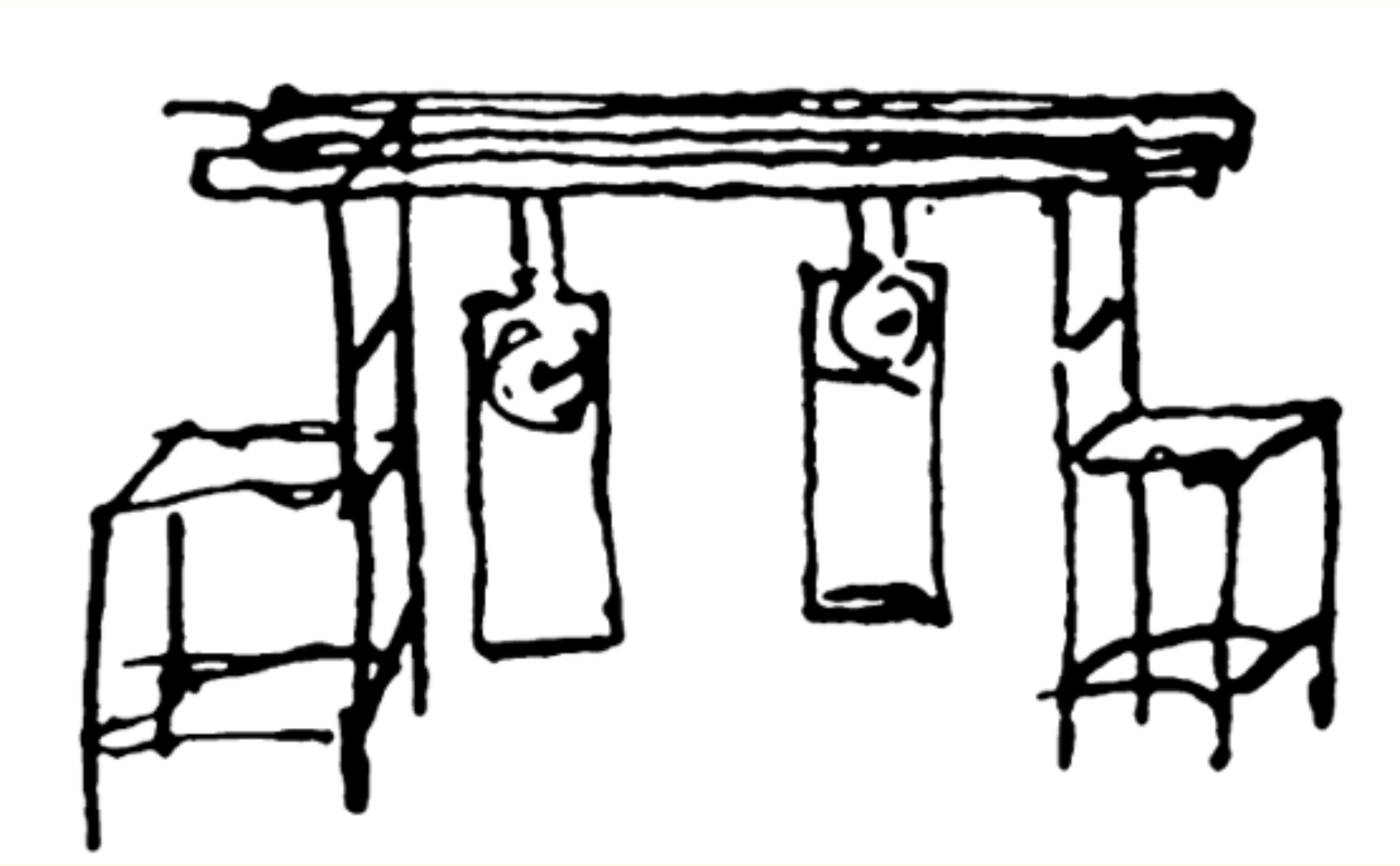




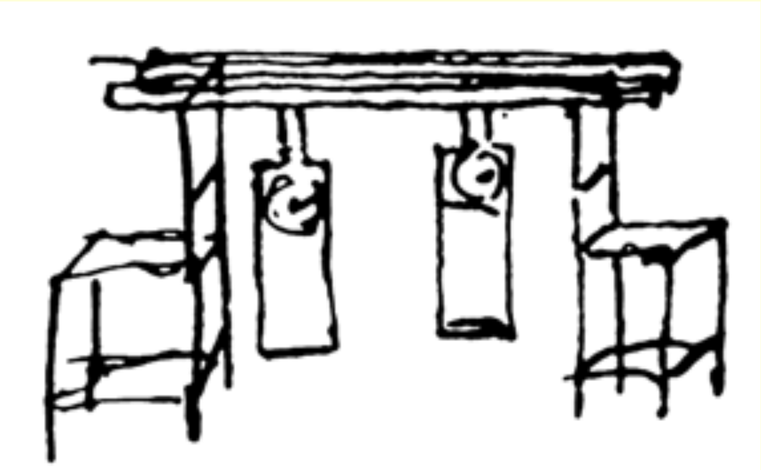
Christiaan Huygens, 1656

Christiaan Huygens: mutual sympathy of clock





Christiaan Huygens: mutual sympathy of clock II



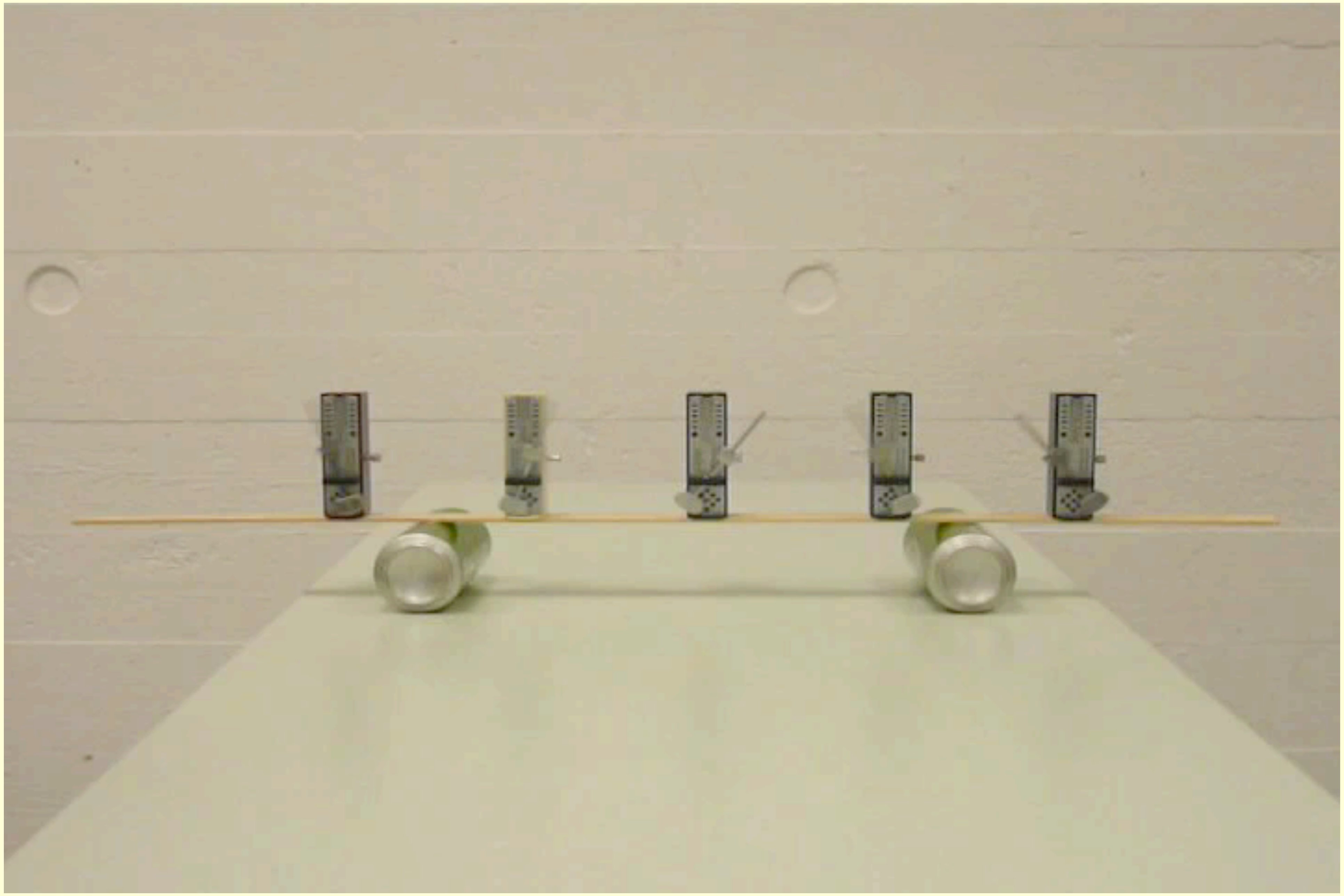
...It is quite worths noting that when we suspended two clocks so constructed from two hooks imbedded in the same wooden beam, the motions of each pendulum in opposite swings were so much in agreement that they never receded the least bit from each other and the sound of each was always heard simultaneously. Further, if this agreement was disturbed by some interference, it reestablished itself in a short time. For a long time I was amazed at this unexpected result, but after a careful examination finally found that the cause of this is due to the motion of the beam, even though this is hardly perceptible.

Christiaan Huygens Horologium Oscillatorium, 1656

Synchronization of many oscillators

Idea: B. Daniels, Diploma thesis, Ohio Weslian University

Synchronization of many oscillators



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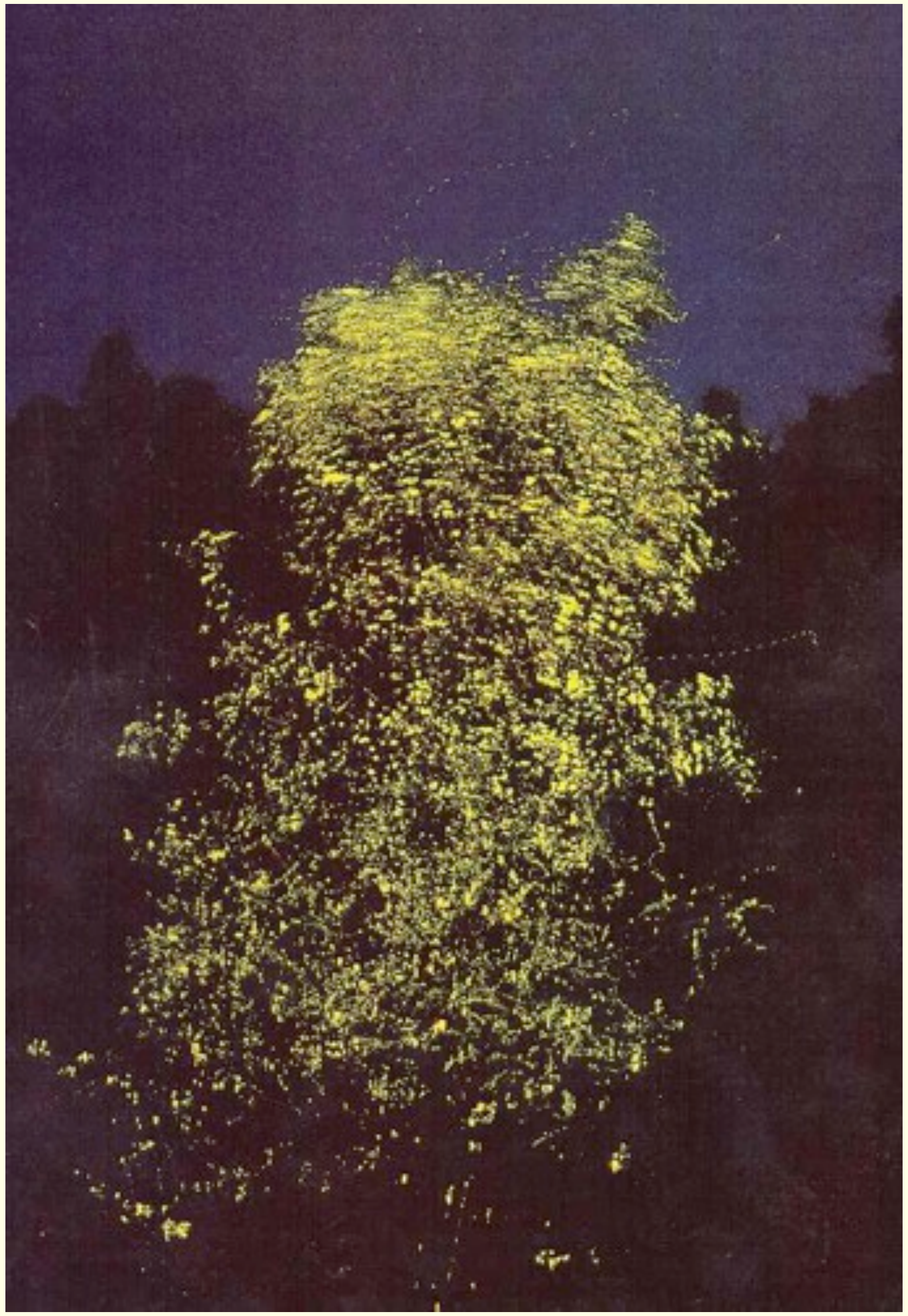


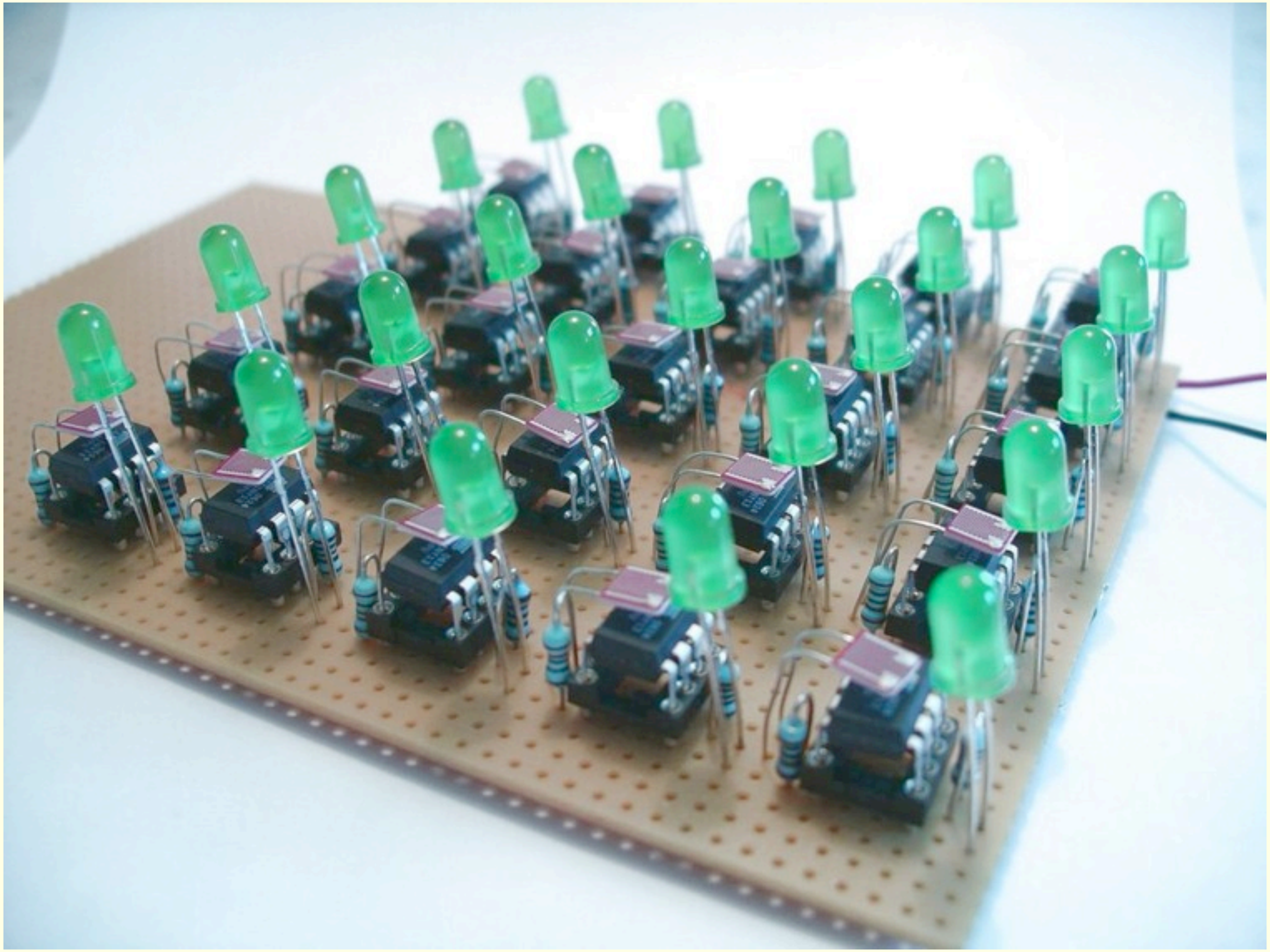
Fireflies synchrony

Engelbert Kaempfer, 1680

Norbert Wiener:

same mechanism is responsible for generation of alpha-rhythms

Electronic “Fireflies”



Electronic “Fireflies”: synchronization

Electronic “Fireflies”: synchronization

“Bikeflies”

“Bikeflies”

1000 FIREFLIES

1,000
Fireflies

Share:

1050 W Wilson, Chicago, IL 60640

Buy your synchronizing bike light here and participate! For the September 27 Chicago premiere of The Kuramoto Model (1,000 Fireflies), 250 custom bike lights will be distributed to cyclists attending the EdgeUp festival, part of Chicago Artists Month. Using radio communication, these devices synchronize their blinking patterns with other nearby devices, altering social rules of proximity and generating a nomadic self-organizing system.

[HTTPS://SQUAREUP.COM/MARKET/1-000-FIREFLIES](https://squareup.com/market/1-000-fireflies)

Pedestrian synchrony on footbridges

Millennium Bridge, London, river Thames

Millennium Bridge, opening day

Film: Arup Group Limited

Millennium Bridge, opening day

Film: Arup Group Limited

Synchronization vs. resonance

Film: Arup Group Limited

Synchronization vs. resonance

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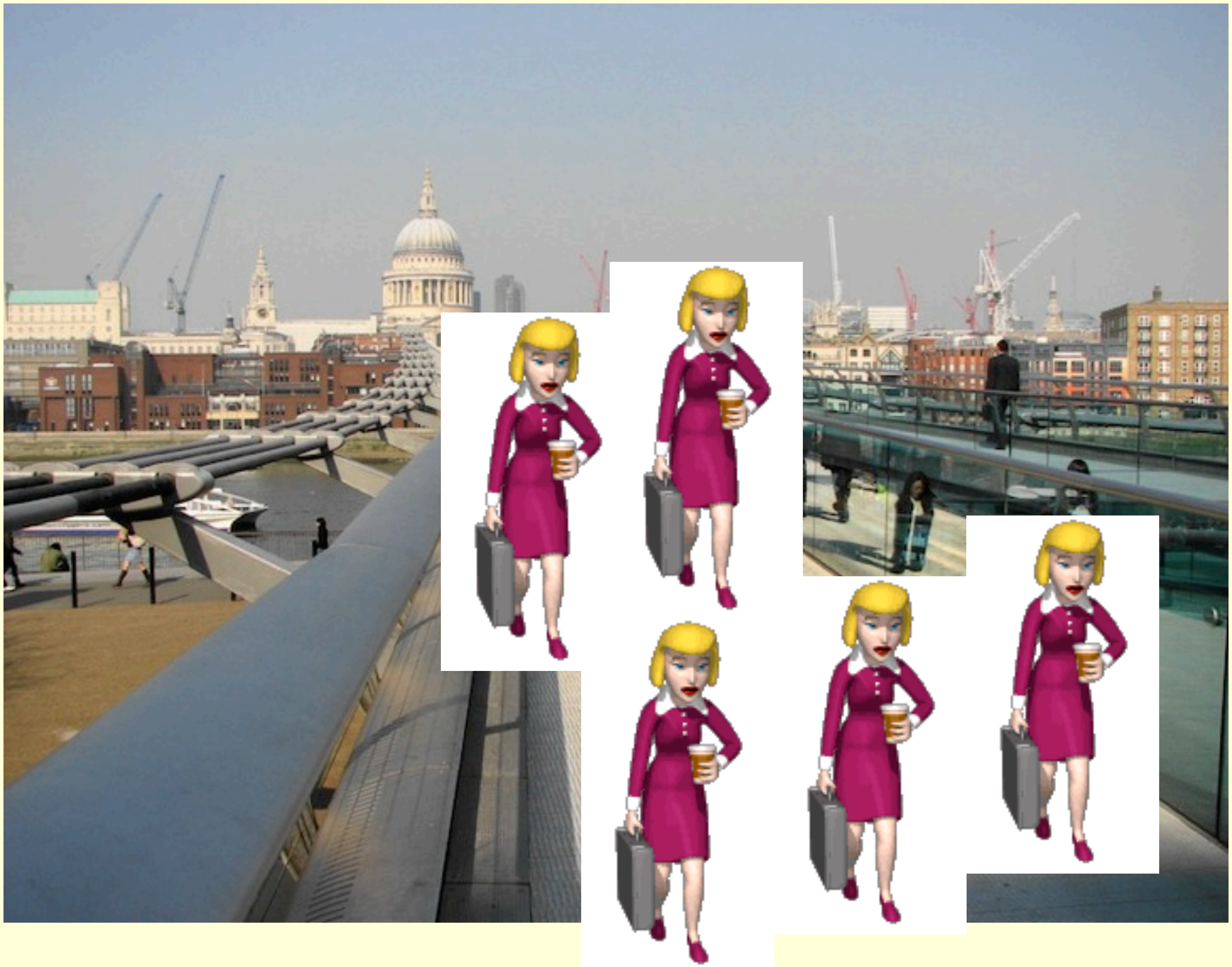
Synchronization vs. resonance II

Resonance: The force originally exists, the system (the bridge) responds to it



Synchronization vs. resonance III

Synchronization: Originally there is no force, but it emerges due to self-organization

Synchronization: main problems

1. Externally forced oscillator
2. Two mutually coupled oscillators
3. Several coupled oscillators
4. Large population of oscillators
   - regular structures (lattices)
   - fully connected networks
   - complex networks
   - interacting populations (networks)
5. Oscillatory medium
6. Effects of noise
7. Chaotic systems
8. Experimental studies
9. Application to data analysis

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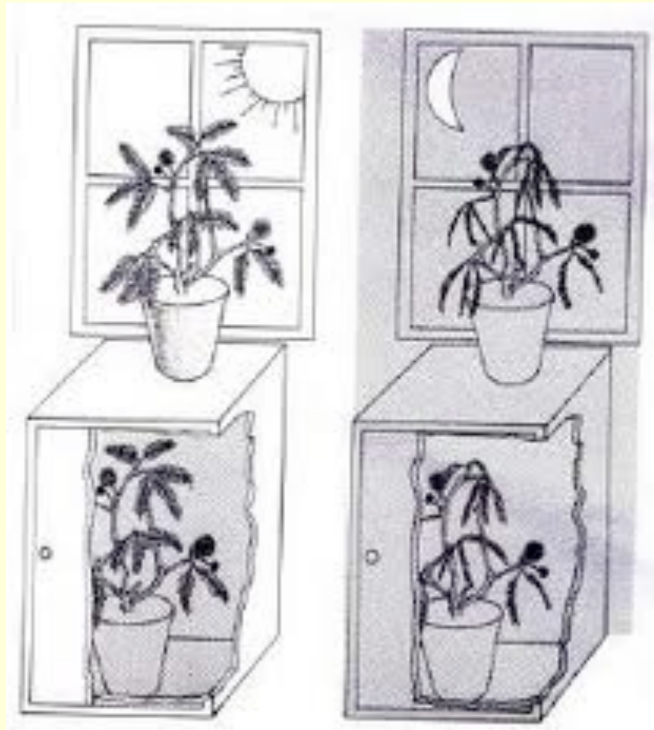
Entrainment by an external force: circadian rhythms

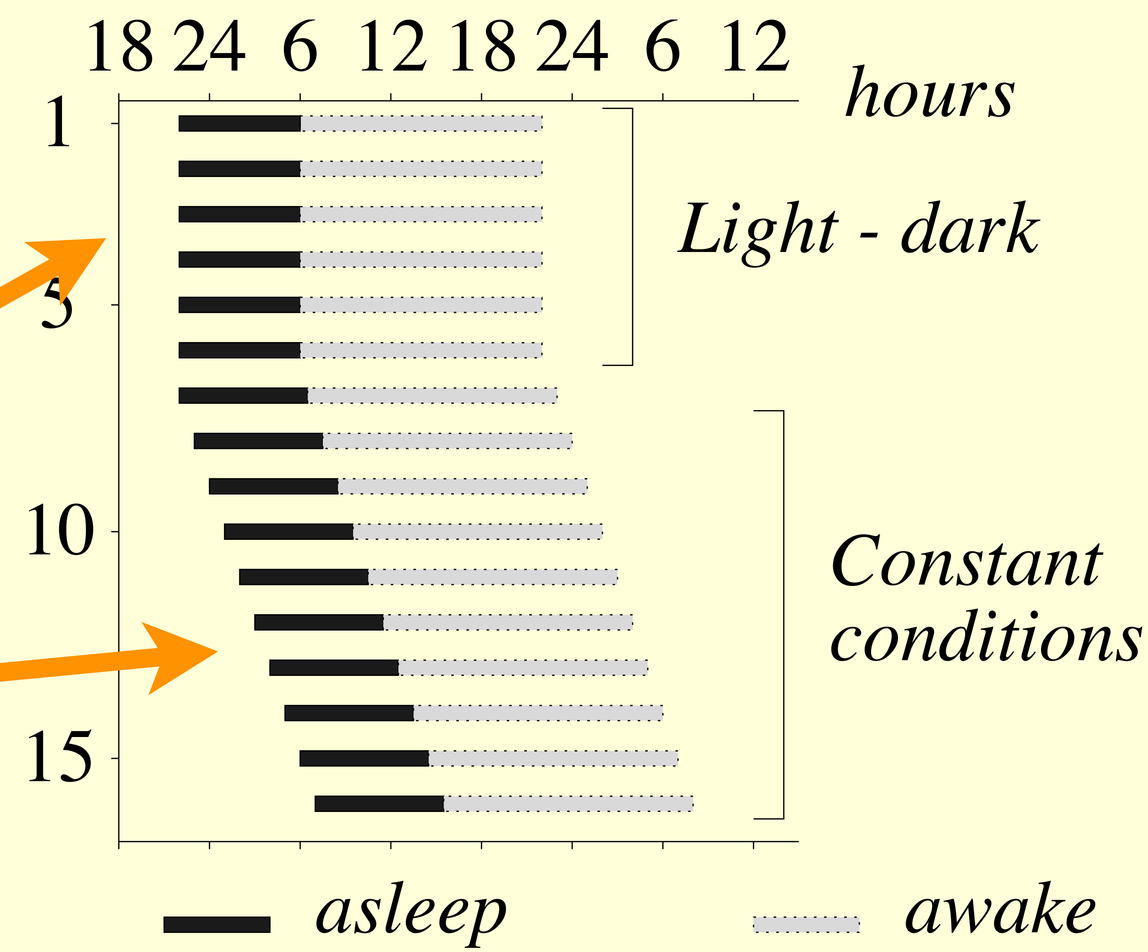


Motion of leaves of a plant in the darkness: evidence for the existence of the inner clock (circadian rhythm)

Jean-Jacques d'Ortous de Mairan, 1729

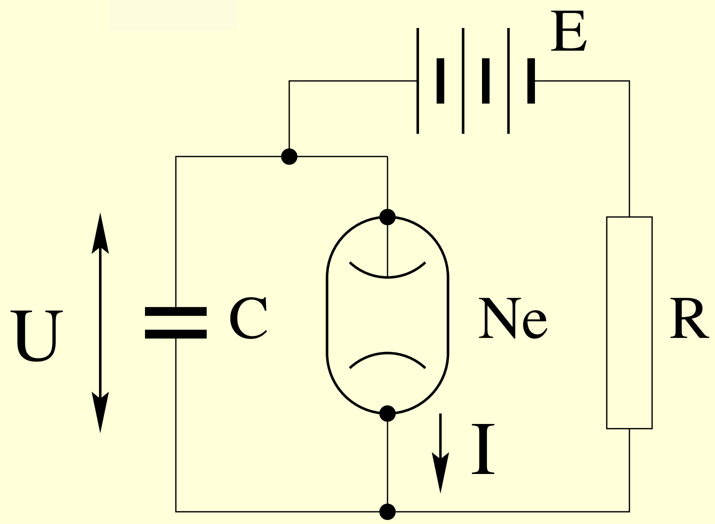
Inner clock is locked to the light-dark cycle

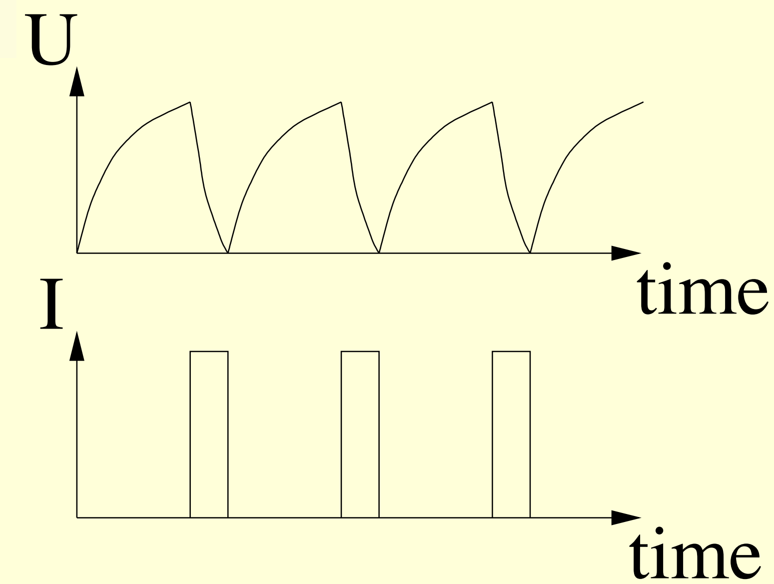
Loss of synchrony

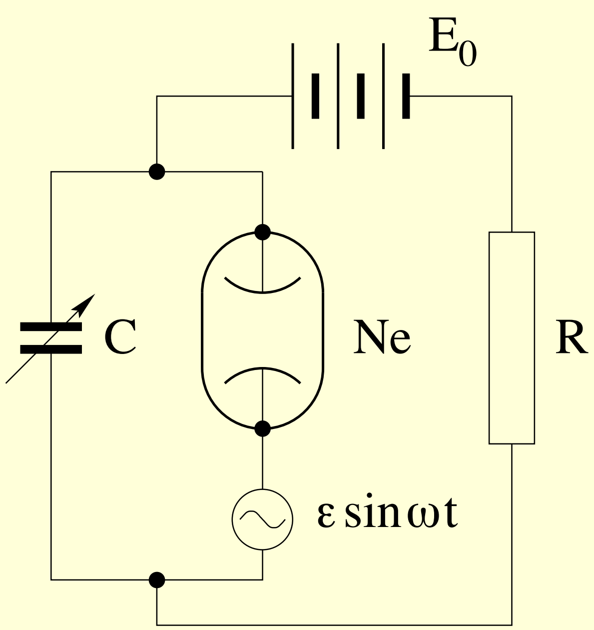


Entrainment by an external force: neon tube oscillator

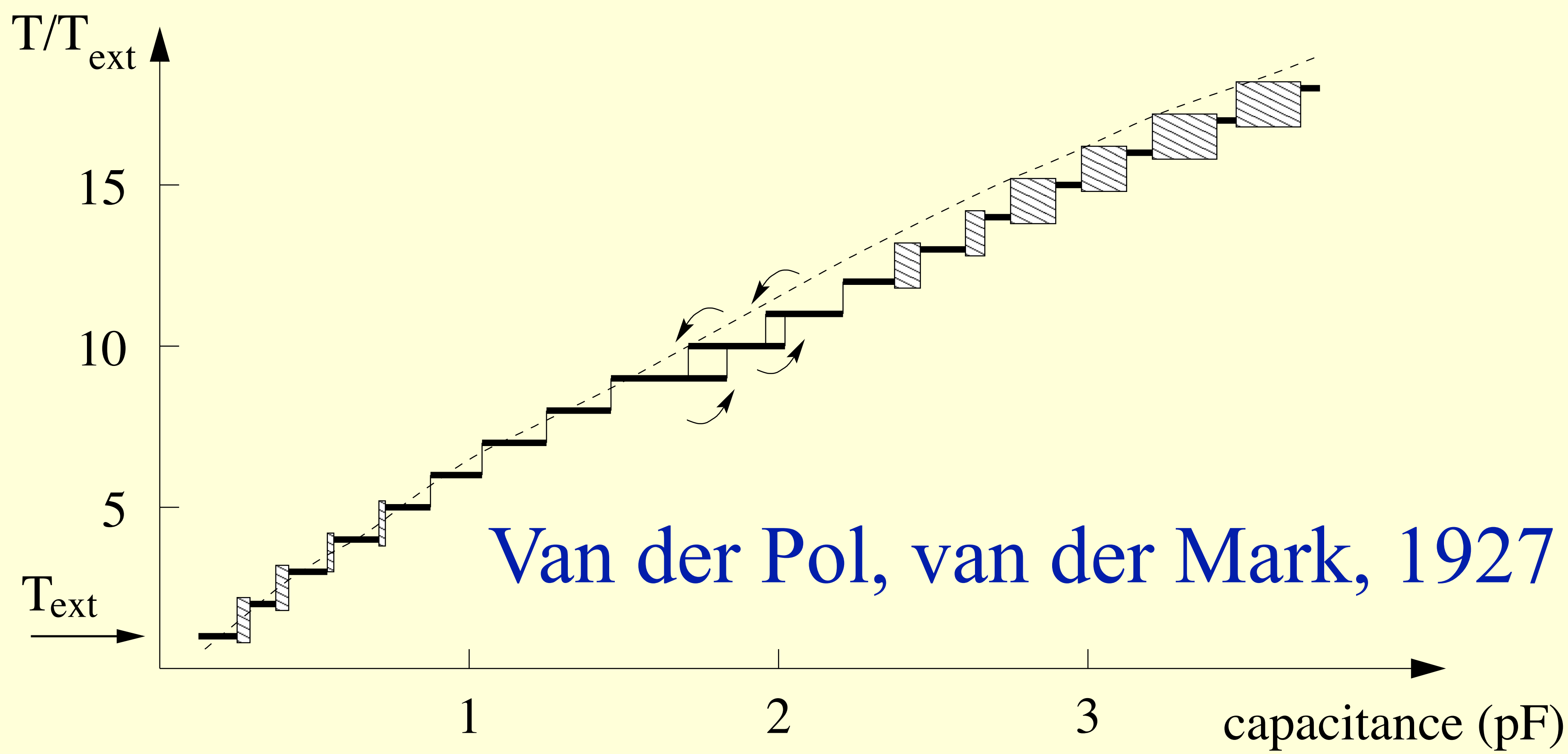
Van der Pol, 1926





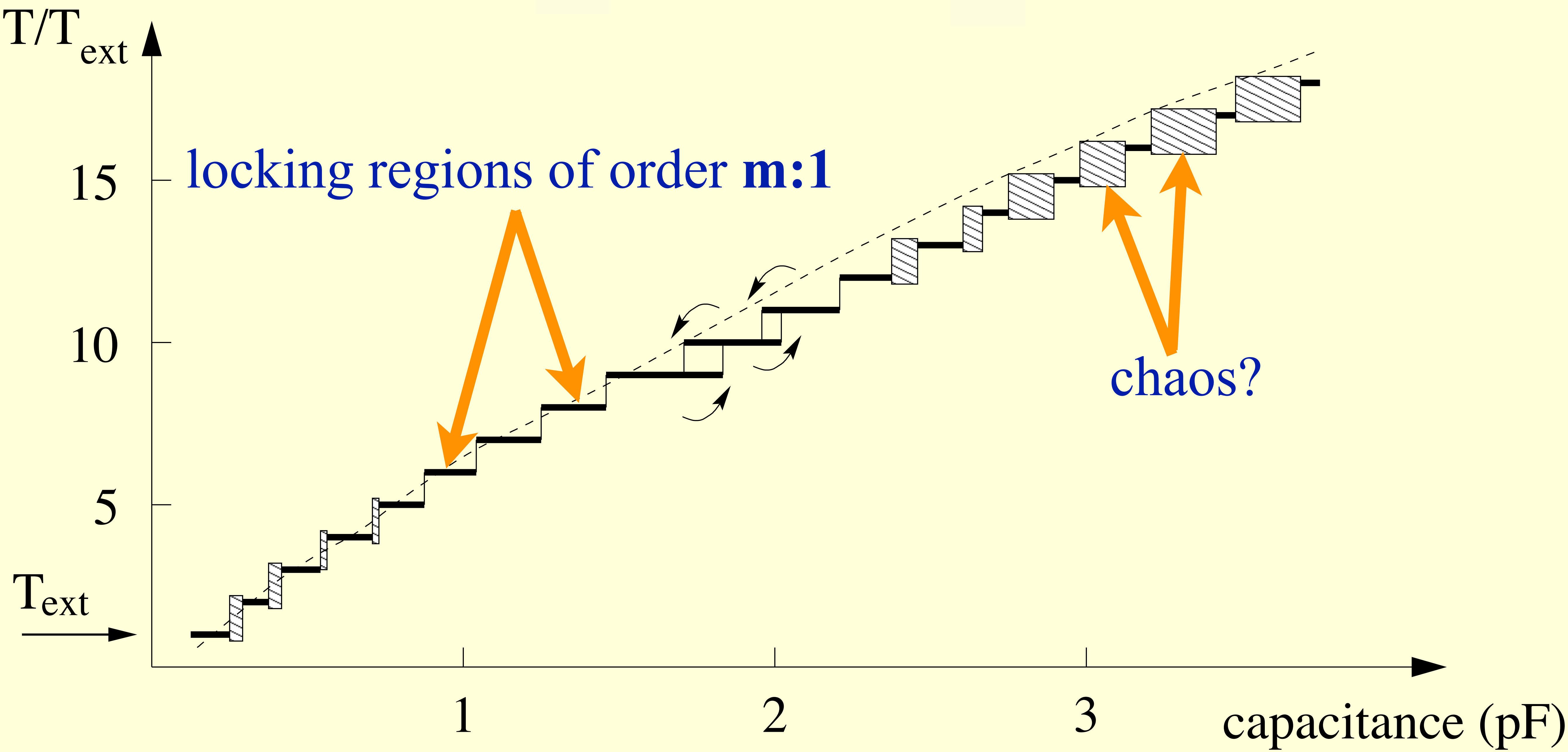


forced system

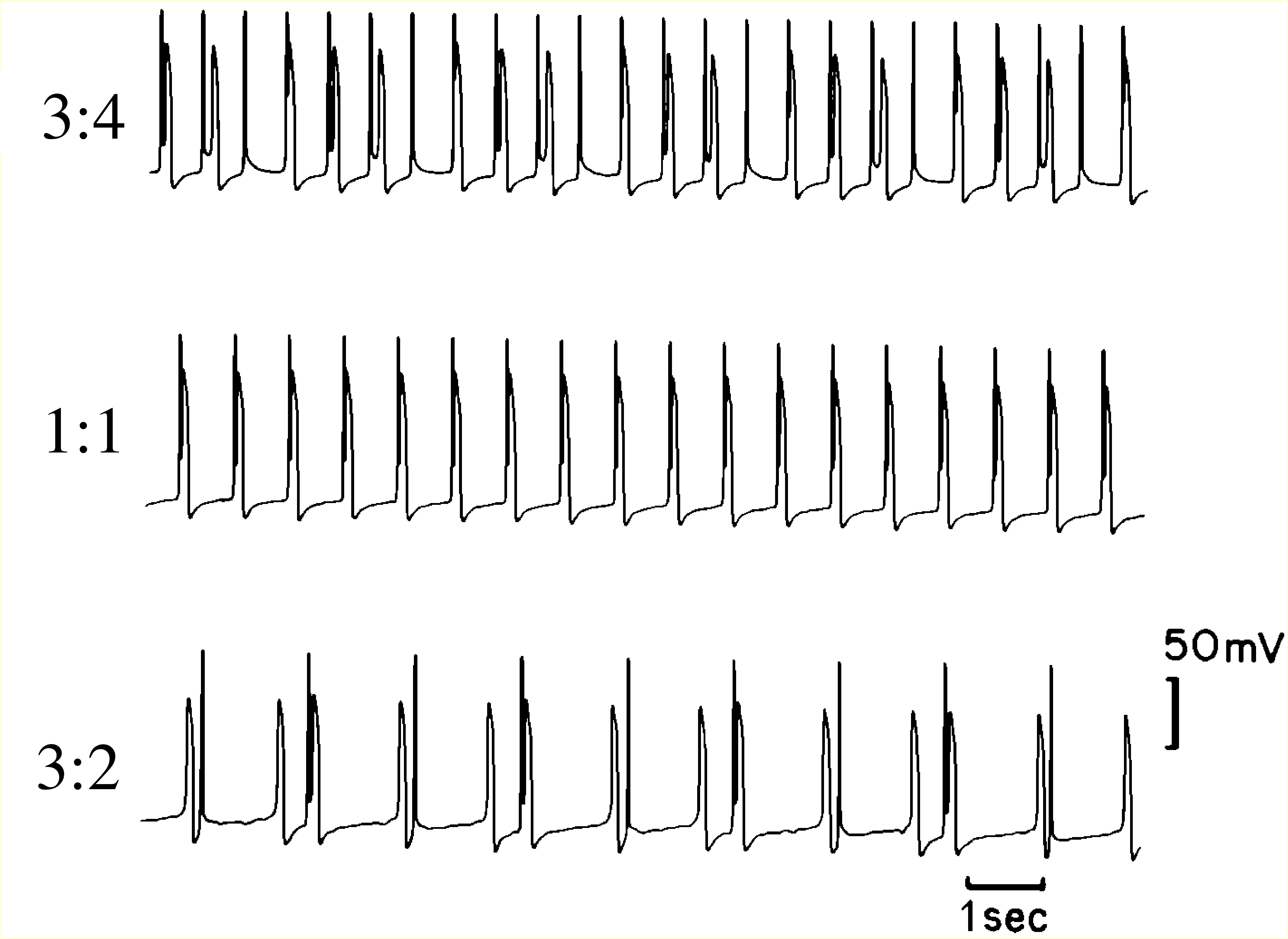


Van der Pol, van der Mark, 1927

Entrainment by an external force: neon tube oscillator



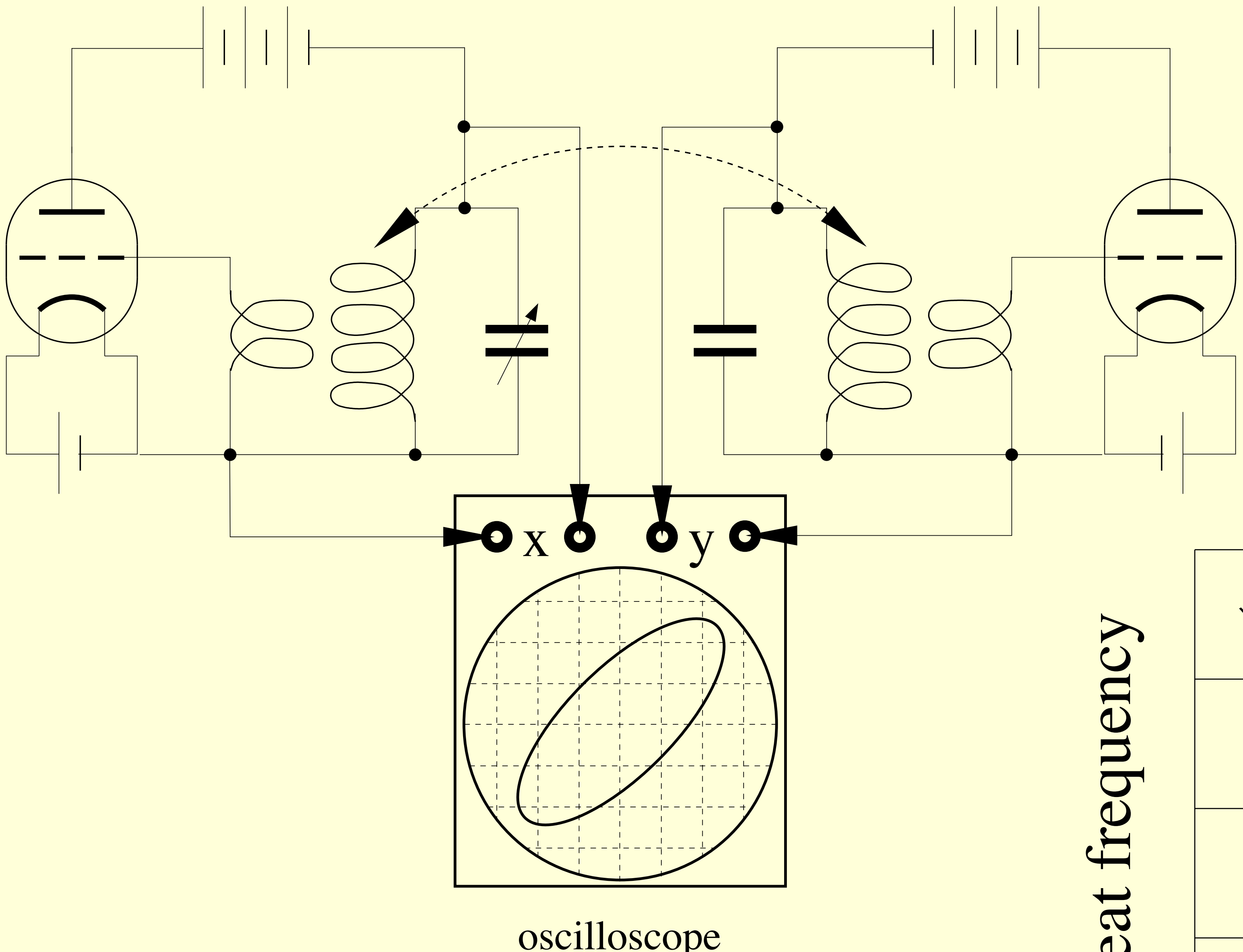
Entrainment by an external force: n:m locking

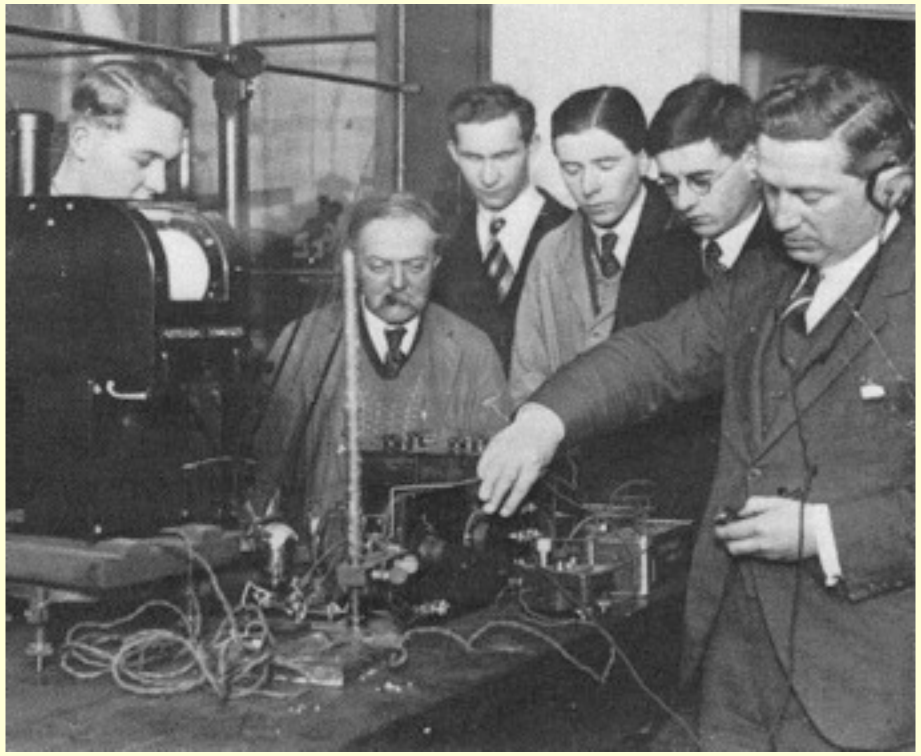


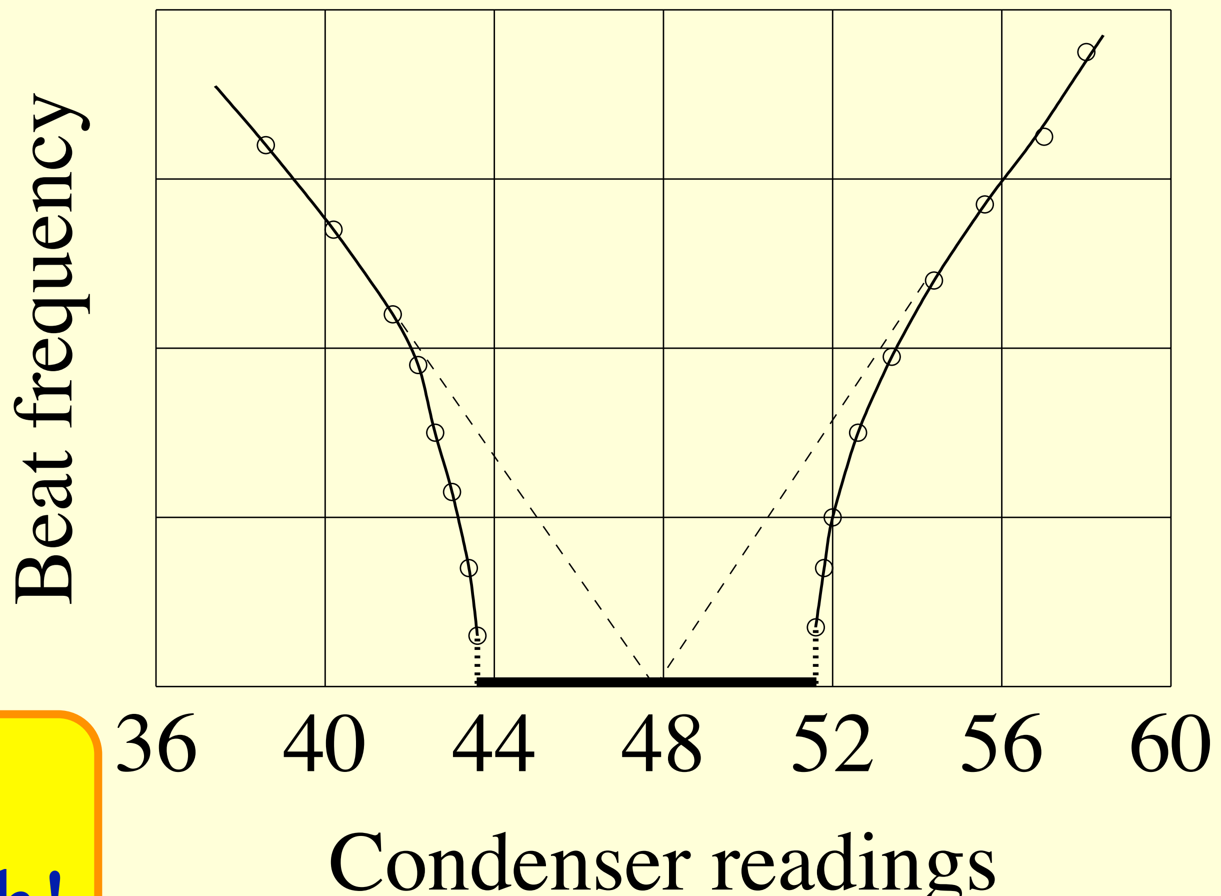
Zeng et al., 1990

Stimulation of embryonic chick atrial heart cells

Two mutually coupled oscillators: classical experiment by Appleton, 1922







Condition of locking is fulfilled for
a finite range of frequencies mismatch!

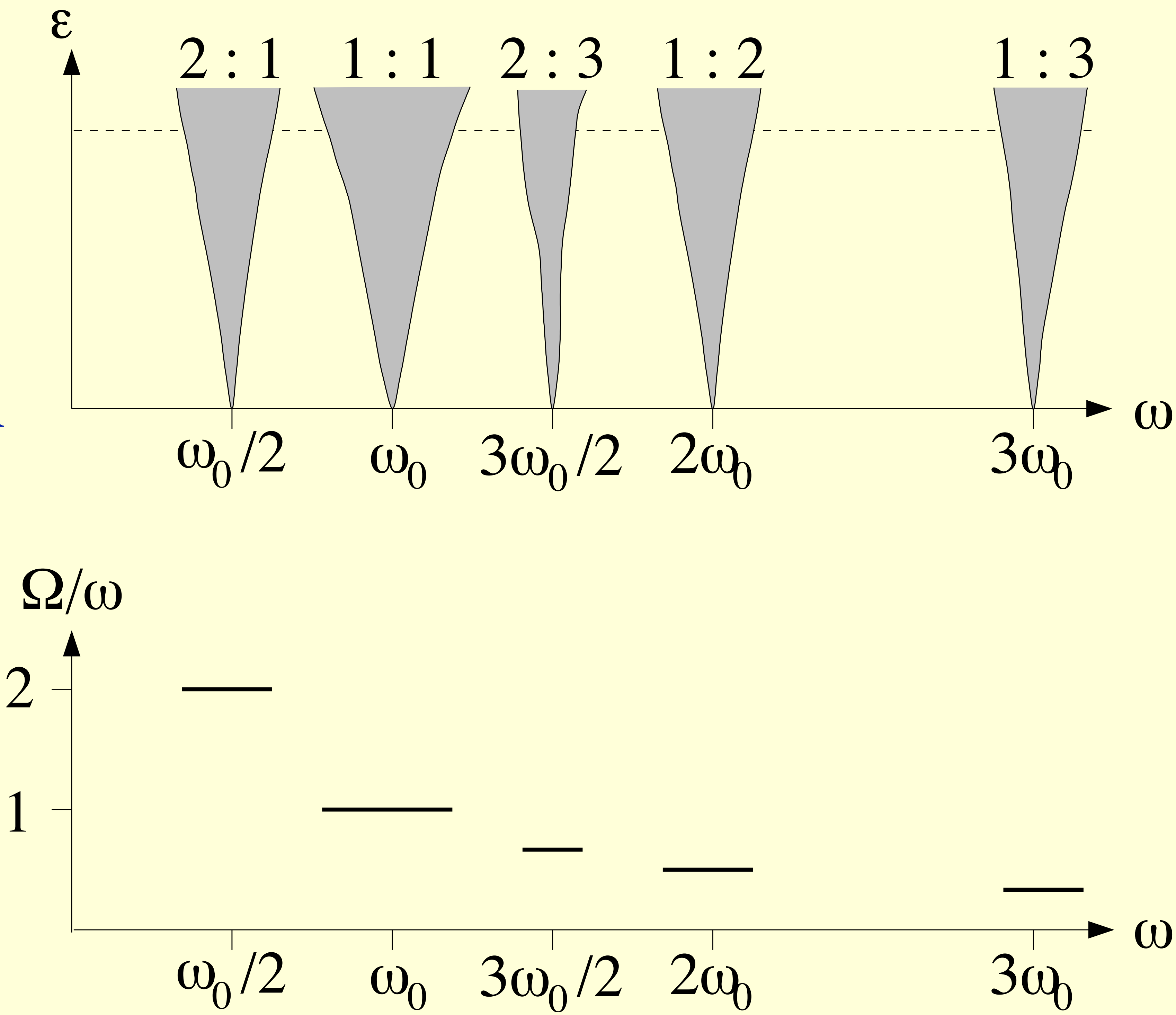
Frequency locking: intermediate summary

ω: forcing frequency

ε: forcing amplitude

ω_0: frequency of the autonomous system

Ω: frequency of the forced system



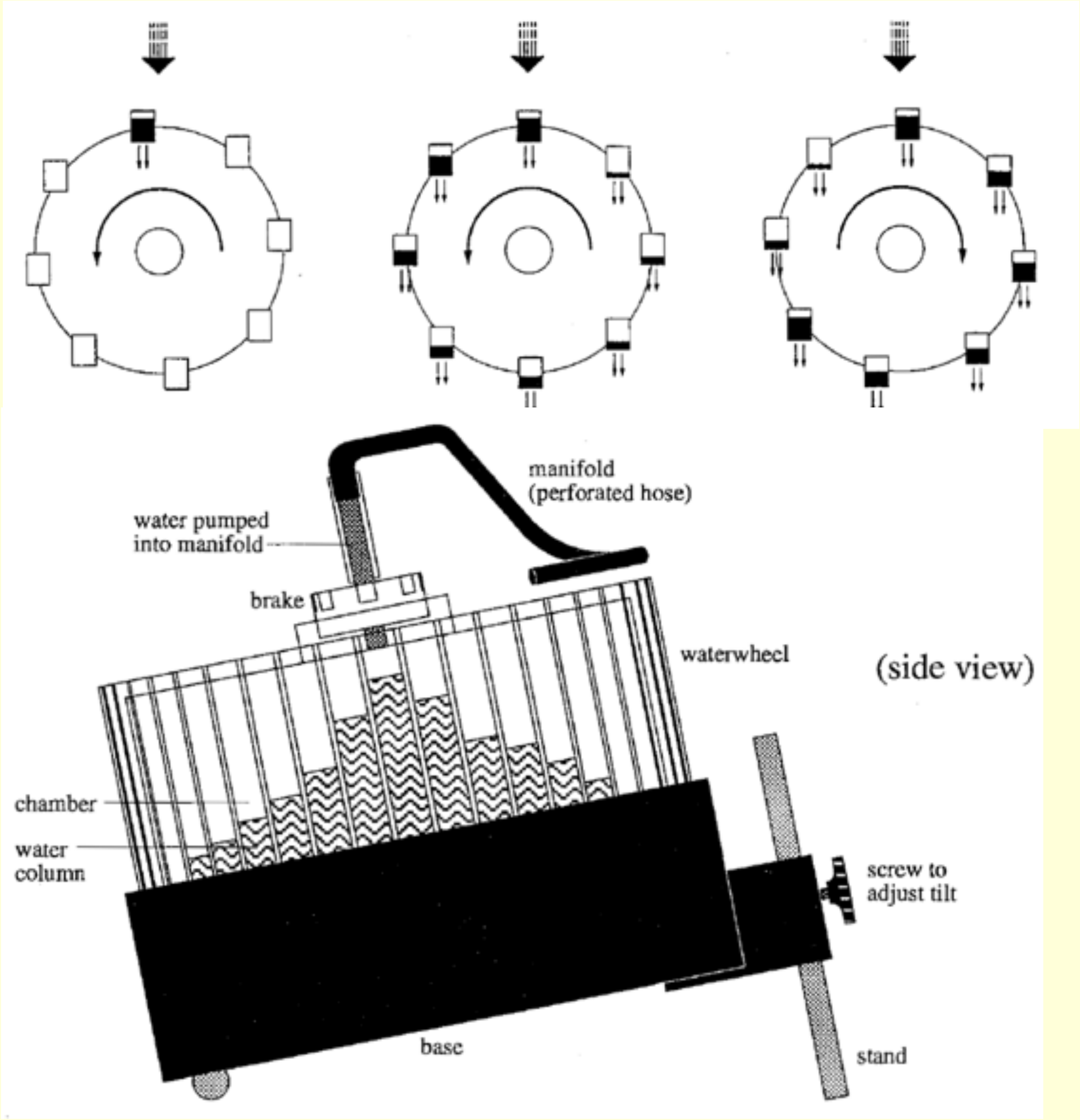
frequency locking:

$$n\Omega = m\omega$$

Same picture for mutual coupling of two systems

Chaotic oscillators

Waterwheel



S. Strogatz, Nonlinear dynamics and chaos

Can chaotic systems synchronize? Yes!

Chaotic oscillators

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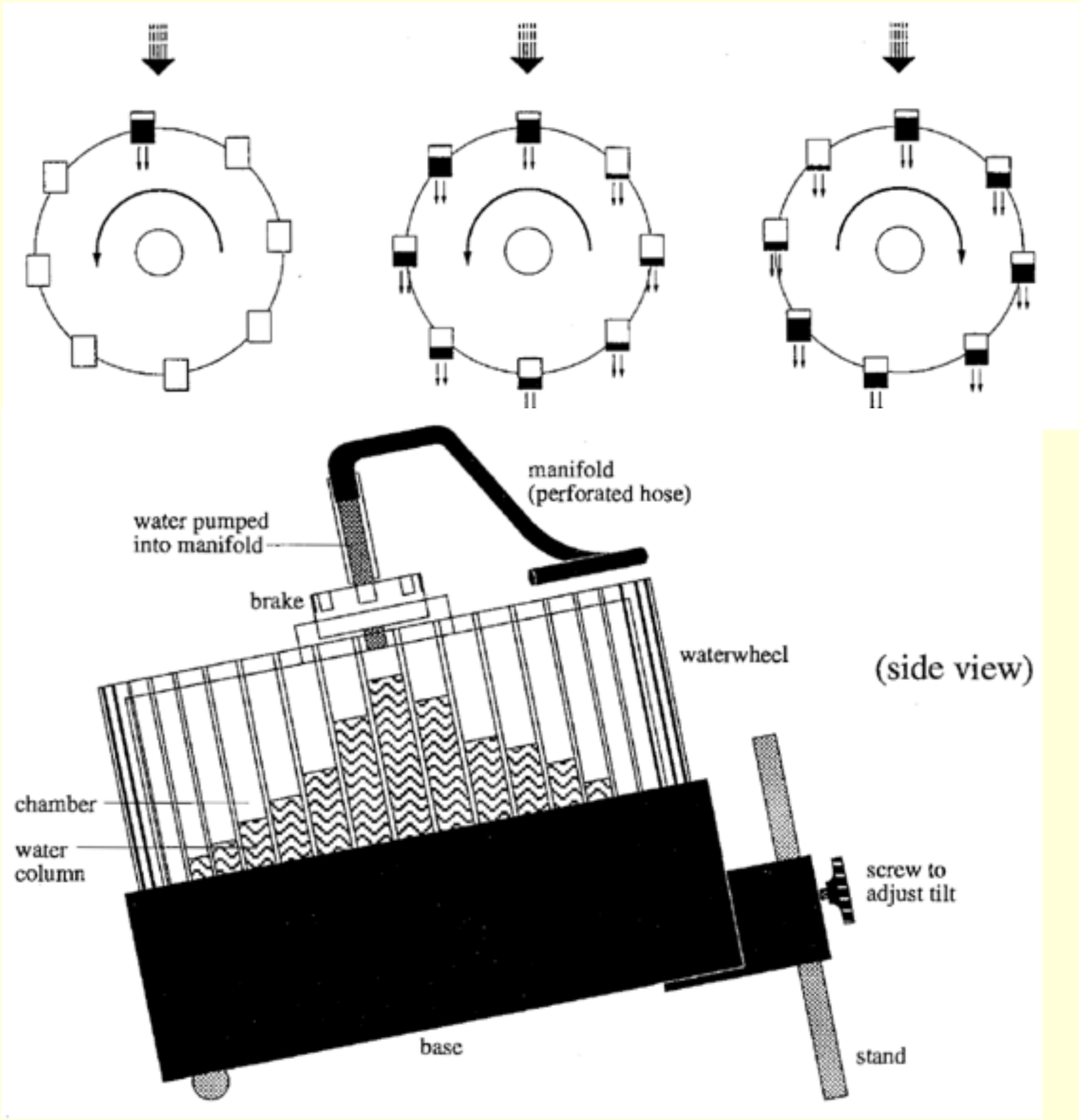

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