Title: Physics in Nature Presentation: Irreversible Processes

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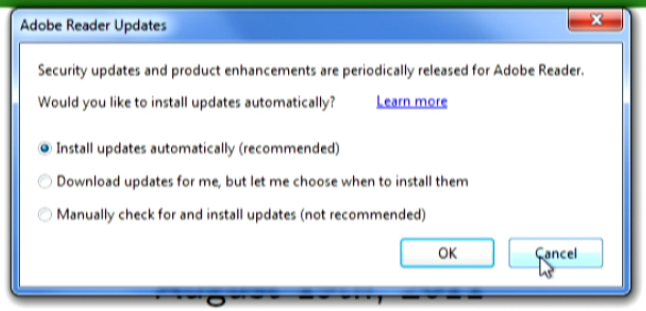
Abstract:

The physics behind sprinklers



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A simple sprinkler

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Examples of irreversible processes in nature

- Sprinklers ;
- Waterfalls ;
- Doppler effect : $f = \left(\frac{v+v_r}{v+v_s}\right) f_0$
- A man crossing and uncrossing his legs?

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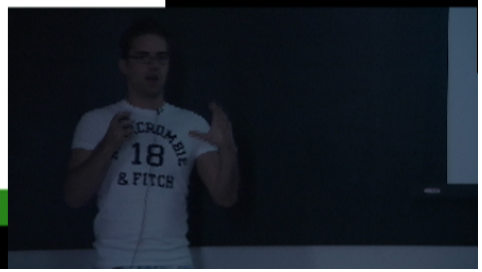

Outline

- Entropy: overview and physical meaning
- Loschmidt's Paradox
- The Fluctuation Theorem

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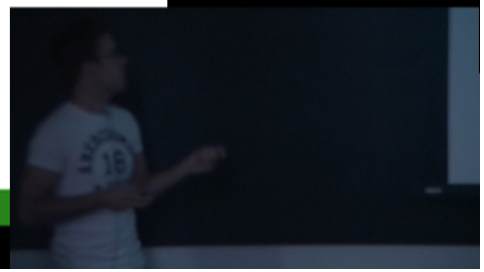
Entropy, an obscure concept

Definition: A small change in entropy may be defined as $dS \equiv \frac{\delta Q}{T}$.
Macroscopically, we can view entropy as:

- the availability of a system's energy to do work



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Entropy, an obscure concept

Microscopically, entropy is the measure the disorder of a system. It has to do with the quantity of available states Ω in a system.

Boltzmann's formula: $S = k_B \ln \Omega$

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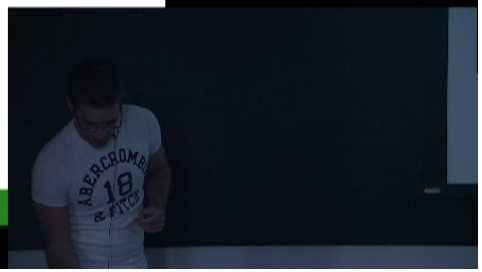
Boltzmann's formula: $S = k_B \ln \Omega$

$\Rightarrow$ 2nd law of thermodynamics = statistical law
Equilibrium = Perfect Internal Disorder (dye in water, air in a box)

Example: P(N particles in one half of box) $= \frac{1}{2^N} \rightarrow 0$ if N large.



Loschmidt's Paradox

Paradox: Irreversible processes should not be deduced from time-symmetric dynamics. Yet, it happens.

H-Theorem: S can only increase in time for an ideal gas.

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- Introduces a time asymmetry
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Question: Is there a way to formally deduce irreversible processes from time-reversible dynamics?

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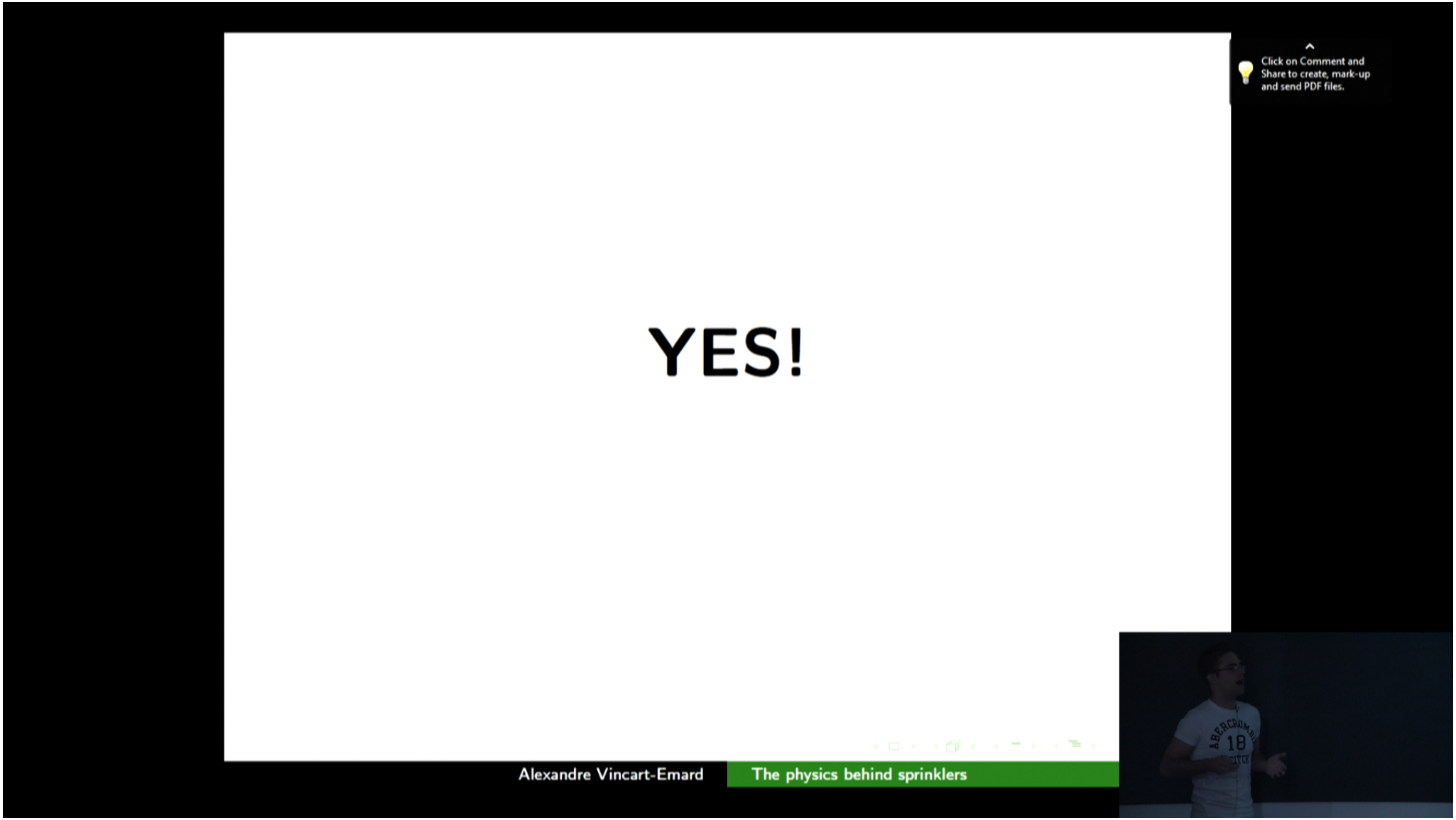
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YES!
Alexandre Vincart-Emard
The physics behind sprinklers

Crooks' Fluctuation theorem

Statistical "law" $\Rightarrow$ non-zero probability of $\Delta S < 0$.
Can we quantify this probability?

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Turns out we can for a non-equilibrium transformation of states:

Crooks' Fluctuation theorem: Let A and B be two microstates, $\Delta F = F(B) - F(A)$ the Helmholtz free energy difference between these states, and $W_{A\to B}$ the work done by the system while changing states from A to B. Then:

$$\frac{P(A \to B)}{P(A \leftarrow B)} = e^{\beta(W_{A\to B} - \Delta F)}$$

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- Waterfall: energy has been spread out in heat dissipation and sound waves ;
- Sprinkler: work to be done by pressure to reverse flow of water makes the probability ridiculously low ;
- Second law of thermodynamics is statistical and can be broken, but at VERY low probabilities.

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Irreversible processes can be deduced from time-reversible mechanisms !

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