The Essence of Science

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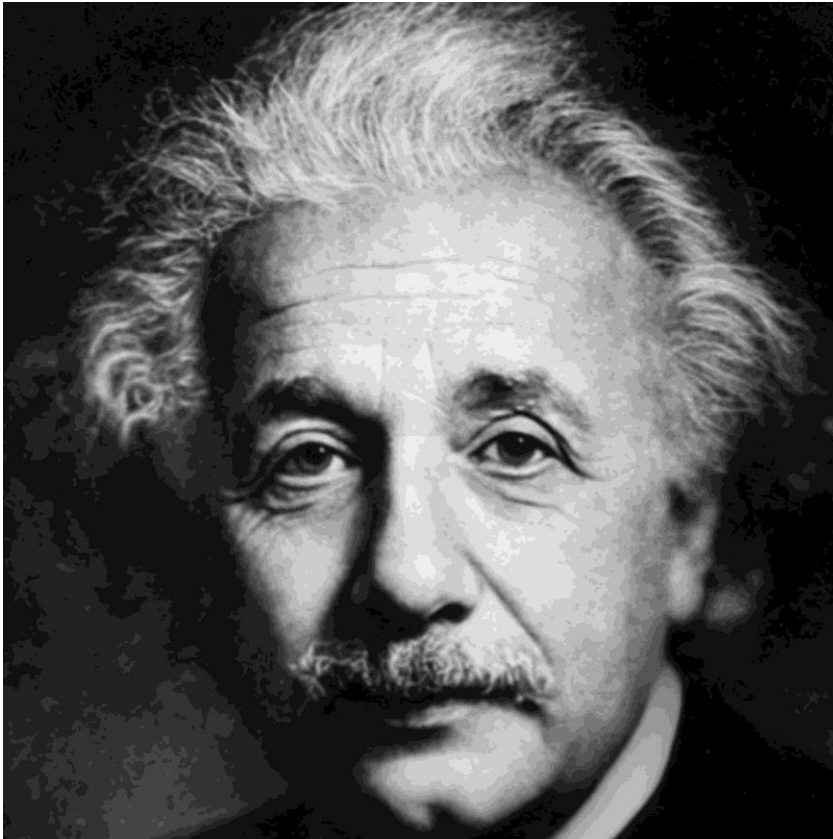Nanomaterials, Catalysis, Electrochemistry (NCE)
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University of Liège

NCE
CHEMICAL ENGINEERING

LIÈGE université

Do you know them ?

Do you know them ?

Albert EINSTEIN (1879-1955)

"In the judgment of the most competent living mathematicians, (???) was the most significant creative mathematical genius thus far produced since the higher education of women began."

Do you know them ?

Felix KLEIN (1849-1925)

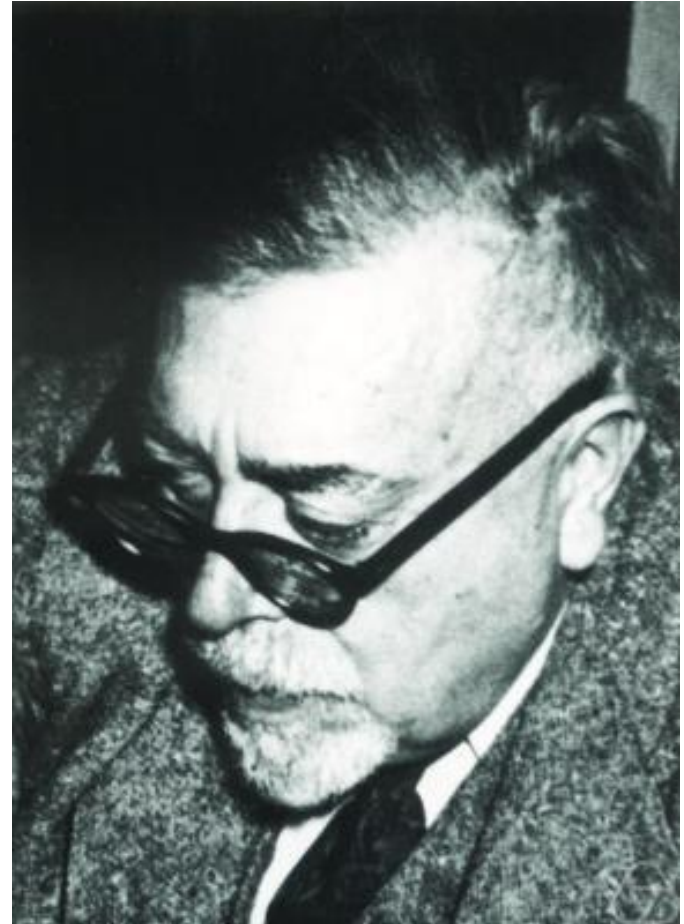David HILBERT (1862-1943)

Do you know them ?

'' I do not see that the sex of a candidate is an argument against her admission as Privatdozent. *After all, we are a university, not a bathing establishment !''*

David HILBERT (1862-1943)

Do you know them ?

"(???) is ... the greatest woman mathematician who has ever lived; and the greatest woman scientist of any sort now living, and a scholar at least on the plane of Madame Curie."

Norbert WIENER (1894-1964)

Do you know them ?

"I was ashamed to occupy such a preferred position beside her, whom I knew to be my superior as a mathematician in many respects."

Hermann WEYL (1885-1955)

Do you know them ?

Emmy NOETHER (1882-1935)

- Born in Erlangen (Germany)
- Jewish family
    - Father was a math professor
- Teacher's certificate
    - French & English
- BUT… she wanted to be a mathematician !
- …
- Became the #**1** in:
    - Abstract algebra (modern algebra)
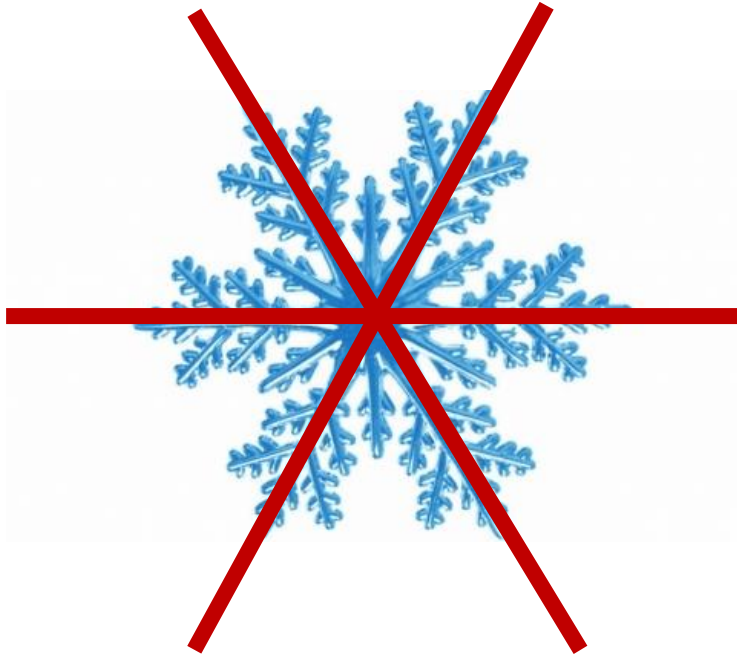   - Theoritical physics

Noether's theorem

Noether's theorem

- Noether's theorem (simplified):

''For every continuous symmetry there exists a conserved quantity''
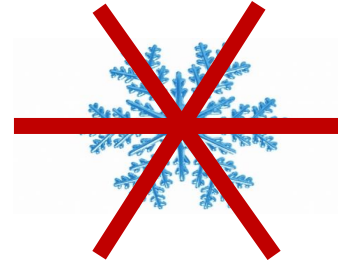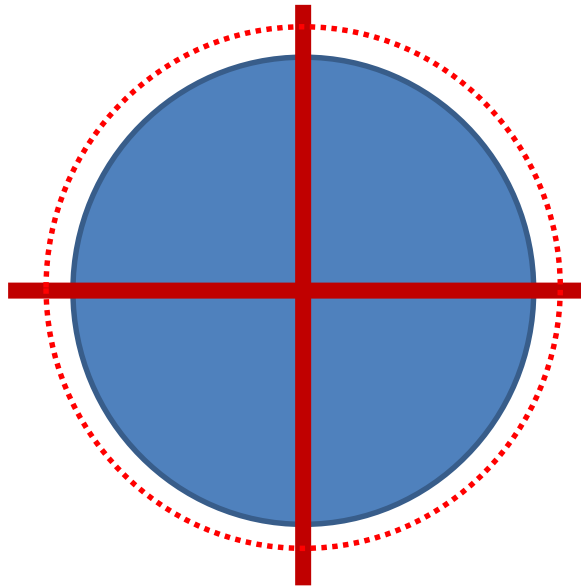
Noether's theorem

Rotational symmetry by 60°

Rotational symmetry by 180°

Noether's theorem

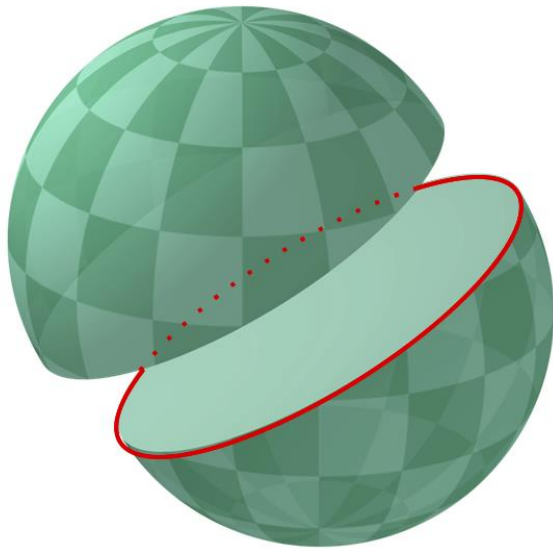- Discrete symmetries

- Continuous symmetries

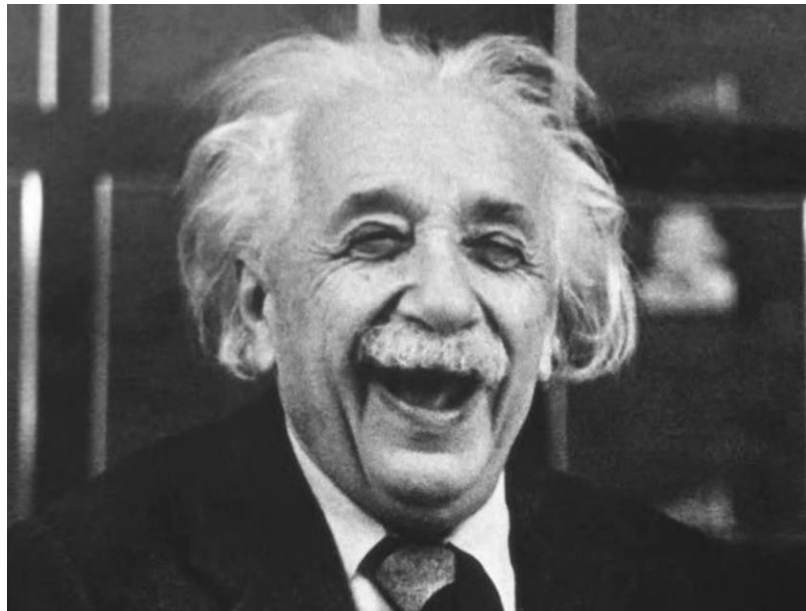Rotational symmetry by 60°

Rotational symmetry by 180°

Noether's theorem

- Discrete symmetries
- Continuous symmetries

Noether's theorem

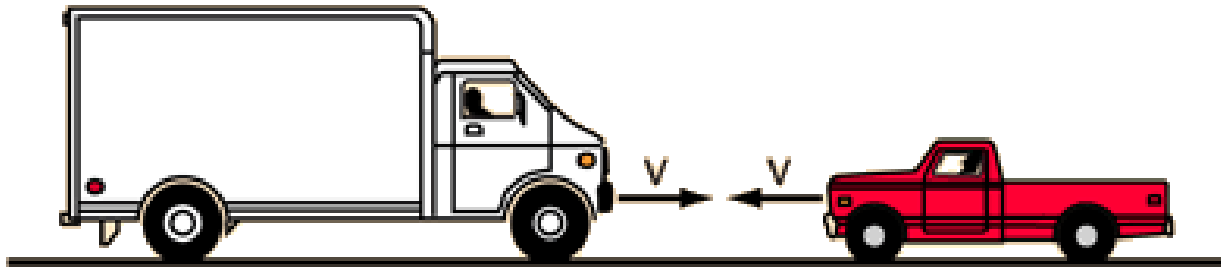- Examples of what we **don't** mean by symmetry in Noether's theorem

Noether's theorem

- Examples of what we **don't** mean by symmetry in Noether's theorem

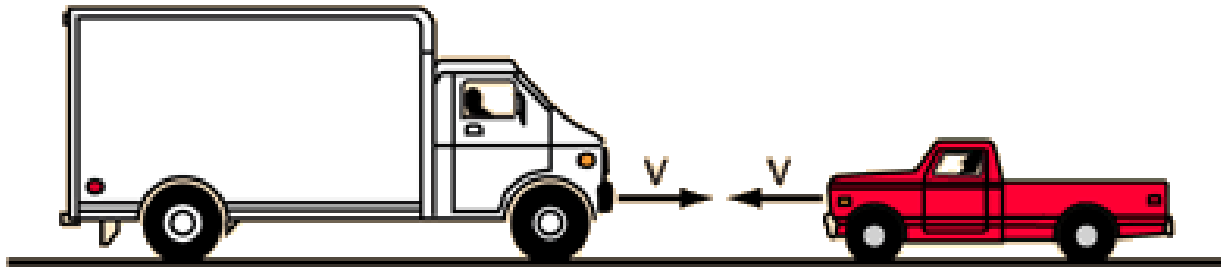- The theorem deals with symmetries of laws of physics !

Noether's theorem

■ Collision (flat road)
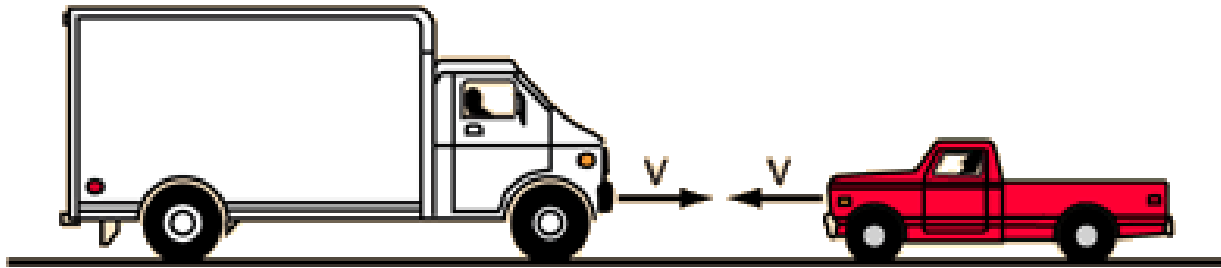
Noether's theorem

- Continuous translational symmetry

Noether's theorem

- Noether's theorem (simplified):

''For every continuous symmetry there exists a conserved quantity''
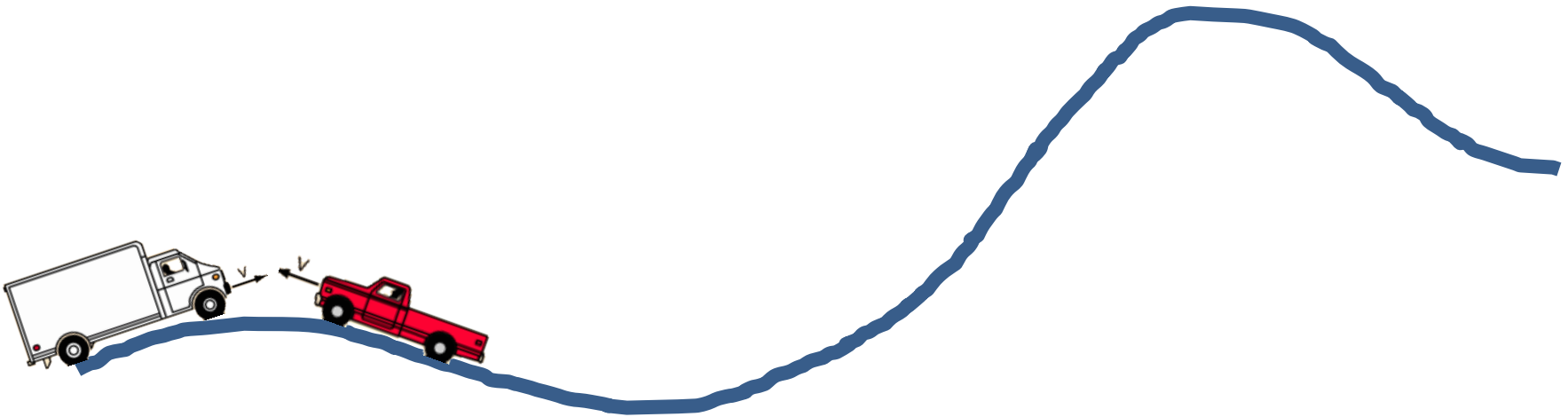
Noether's theorem

- Continuous translational symmetry

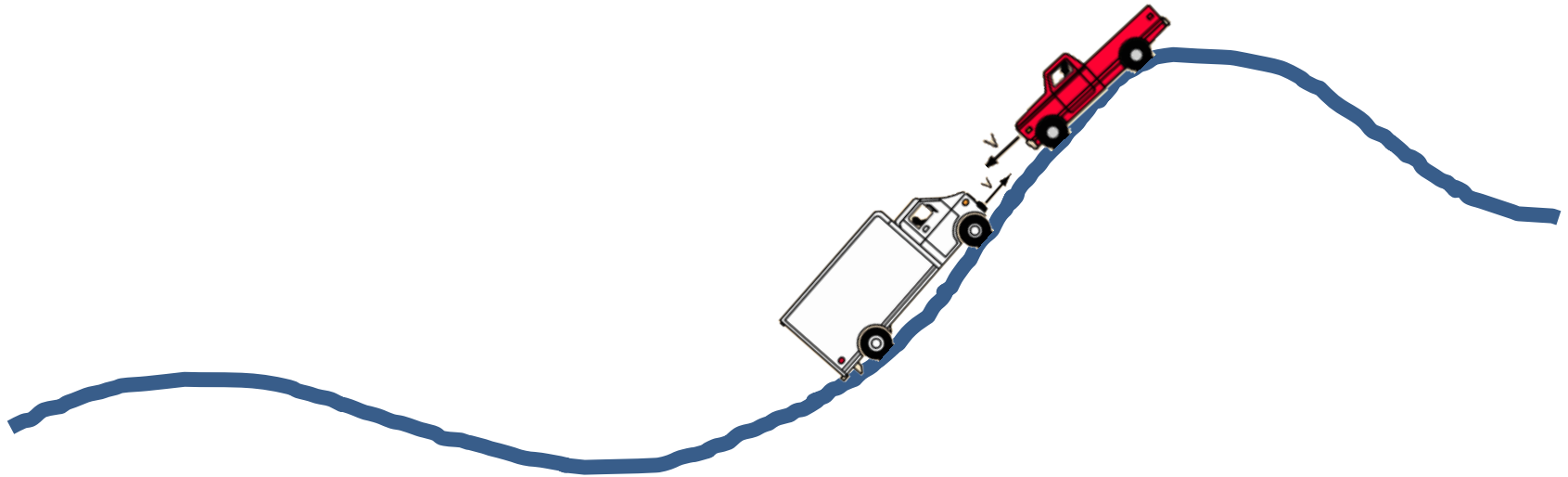- Noether's theorem: **linear momentum**

Noether's theorem
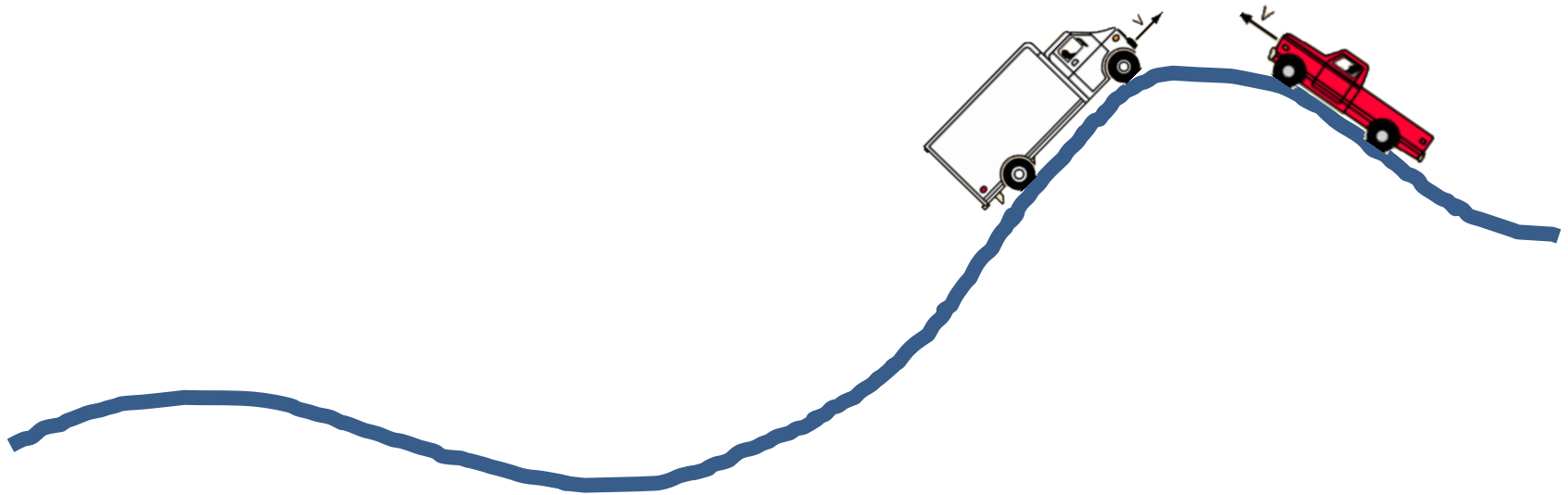
- Collision (hilly road)

Noether's theorem

- Collision (hilly road)

Noether's theorem

- Collision (hilly road)

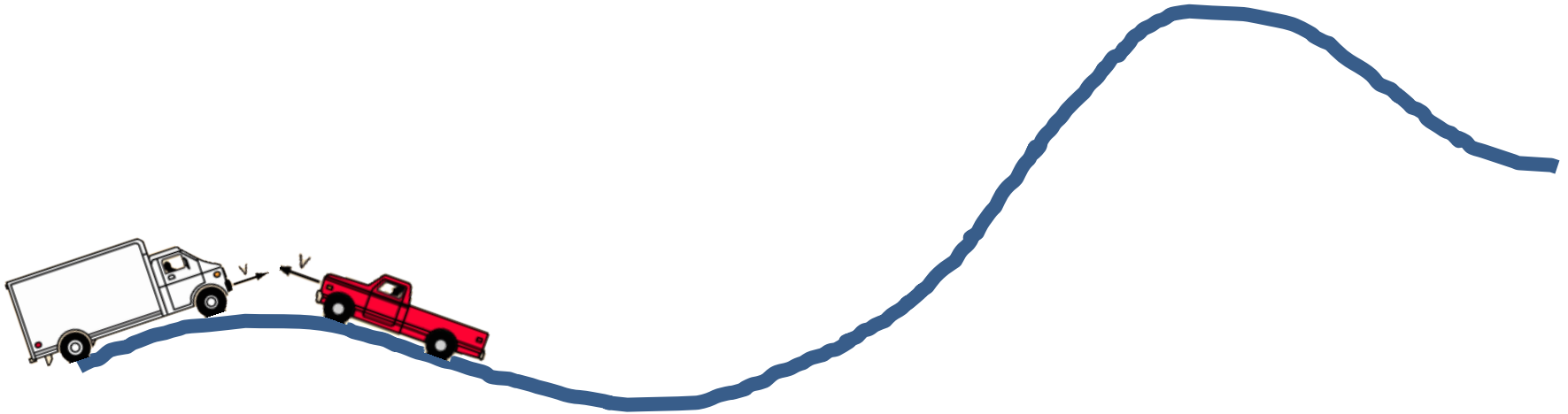# Noether's theorem

- Collision (hilly road)

Noether's theorem

- Collision (hilly road)

Noether's theorem

- Continuous time symmetry

Noether's theorem

■ Noether's theorem (simplified):

''For every continuous symmetry there exists a conserved quantity''

Noether's theorem

- Continuous time symmetry
- Noether's theorem: **energy**

Noether's theorem

- Collision (around the Earth)

Noether's theorem

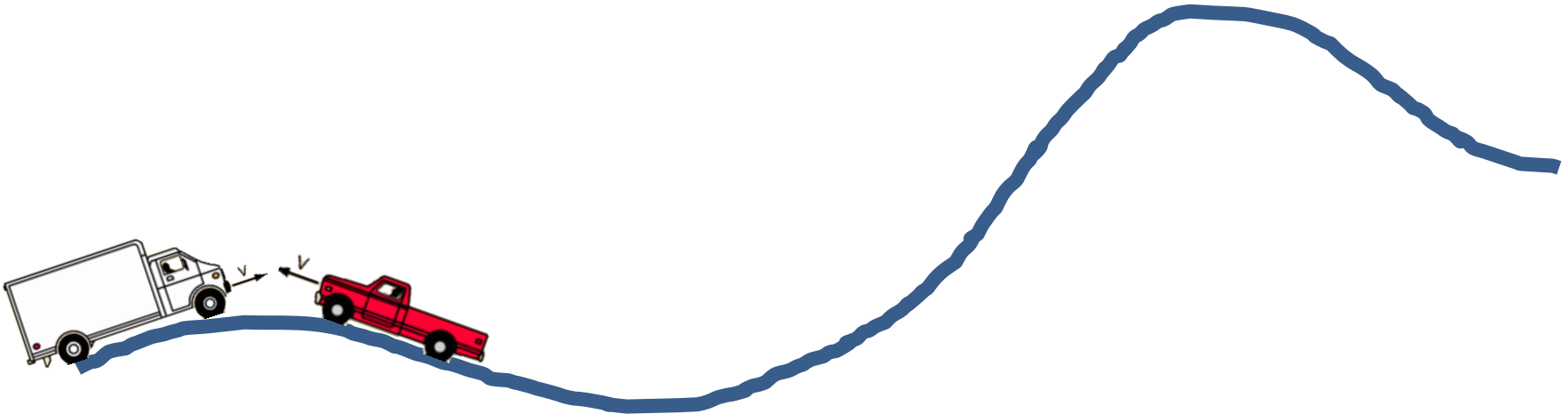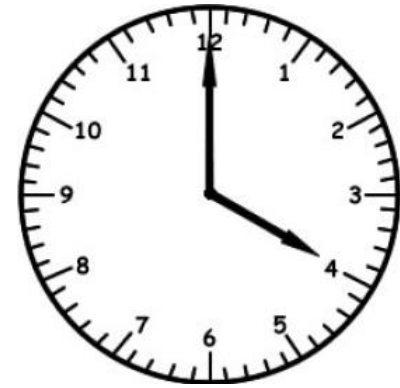- Continuous rotational symmetry

Noether's theorem

- Noether's theorem (simplified):

''For every continuous symmetry there exists a conserved quantity''

Noether's theorem

- Continuous rotational symmetry
- Noether's theorem: **angular momentum**

Noether's theorem

- Noether's theorem (simplified):

of laws of physics

''For every continuous symmetry there exists a conserved quantity''

- Continuous **translational** symmetry → Conservation of **linear momentum**
- Continuous **time** symmetry → Conservation of **energy**
- Continuous **rotational** symmetry → Conservation of **angular momentum**
- **But…**

Noether's theorem

■ Noether's theorem (simplified):

of laws of physics

''For every continuous symmetry there exists a conserved quantity''

■ Continuous **translational** symmetry $\not\rightarrow$ Conservation of **linear momentum**

■ Continuous **time** symmetry $\not\rightarrow$ Conservation of **energy**

■ Continuous **rotational** symmetry $\not\rightarrow$ Conservation of **angular momentum**

■ **But…**

Noether's theorem

- Noether's theorem (simplified):

of laws of physics

''For every continuous symmetry there exists a conserved quantity''

- Continuous **translational** symmetry ↔ Conservation of **linear momentum**
- Continuous **time** symmetry ↔ Conservation of **energy**
- Continuous **rotational** symmetry ↔ Conservation of **angular momentum**

Why the Essence of Science ?

The Essence of Science

- Continuous **translational** symmetry ↔ Conservation of **linear momentum**
- Continuous **time** symmetry ↔ Conservation of **energy**
- Continuous **rotational** symmetry ↔ Conservation of **angular momentum**

''Noether's theorem is a masterpiece of mathematical thinking !''

Thank you !

Want to know more ?

Want ot know more ?

- https://www.youtube.com/watch?v=tbyJWkJnZYk (in French)

- https://www.youtube.com/watch?v=Rqfj7n5aSwY (in English)

- https://www.youtube.com/watch?v=04ERSb06dOg&t=442s (in English)

- http://images.math.cnrs.fr/Noethember.html (in French)

- https://arstechnica.com/science/2015/05/the-female-mathematician-who-changed-the-course-of-physics-but-couldnt-get-a-job/ (in English)

Backslides

Noether's theorem

- Preamble: *How most of the physicists describe the world ?*

- Principle of least action (stationary action)

$$S[\boldsymbol{q}, t_1, t_2] = \int_{t_1}^{t_2} L(\boldsymbol{q}(t), \dot{\boldsymbol{q}}(t), t)dt$$

- L is called the Lagrangian and characterizes the system. S is the action.
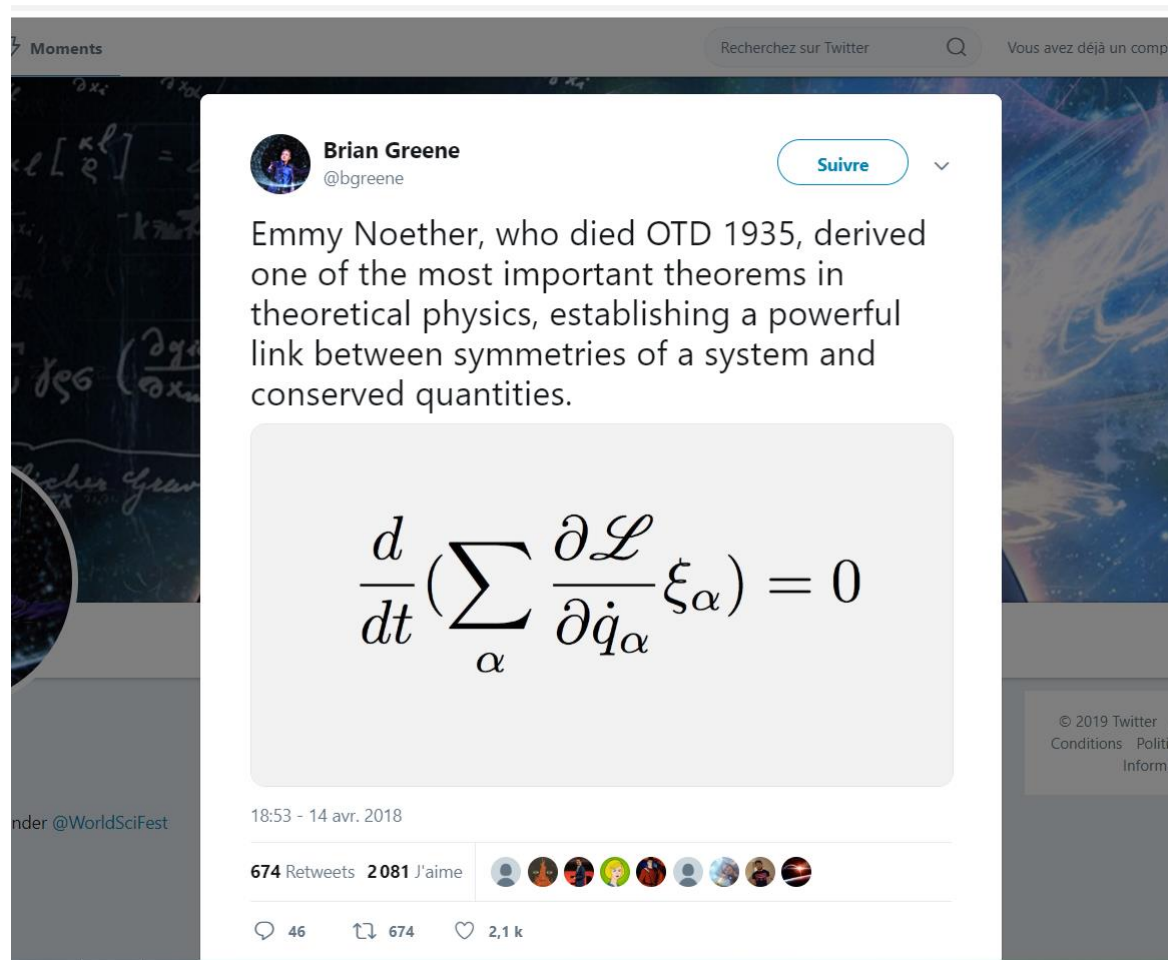
Noether's theorem

- Principle of least action (stationary action)

$$S[\boldsymbol{q}, t_1, t_2] = \int\limits_{t_1}^{t_2} L(\boldsymbol{q}(t), \dot{\boldsymbol{q}}(t), t)\, dt$$

- S has to be minimized $\rightarrow$ $\delta S = 0$
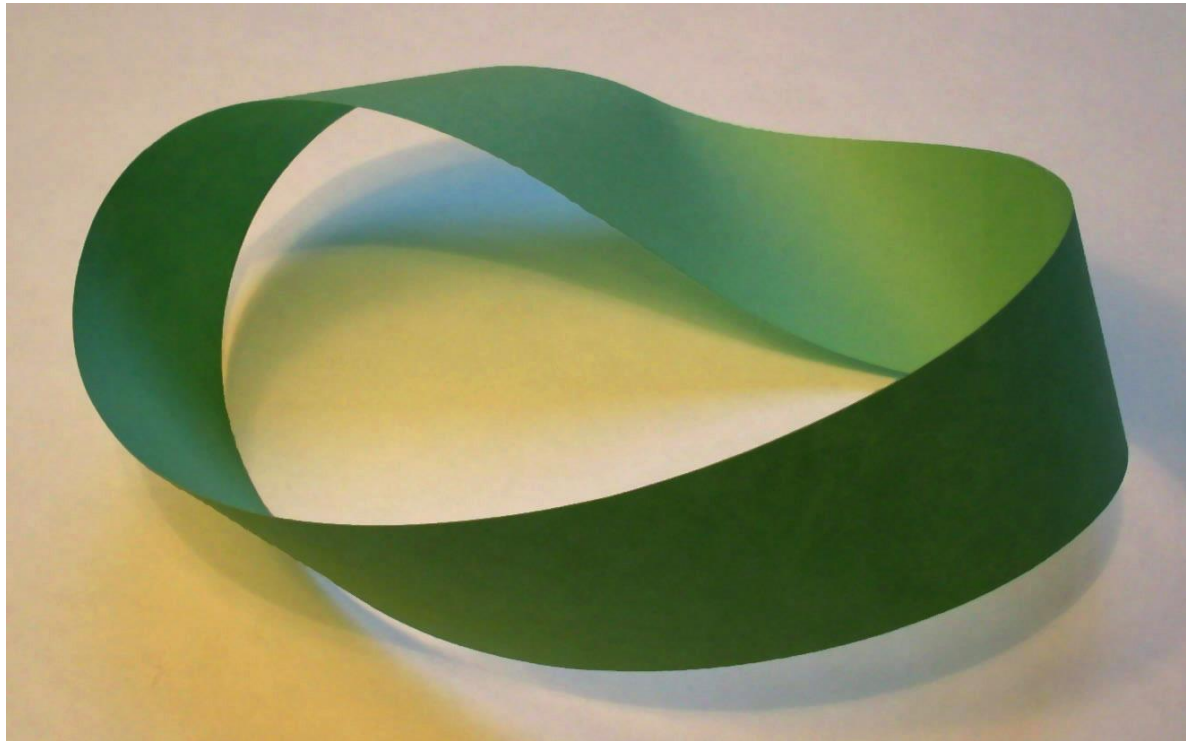
- *Lagrange*'s differential equations

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\boldsymbol{q}}}\right) - \frac{\partial L}{\partial \boldsymbol{q}} = 0$$

Backslides
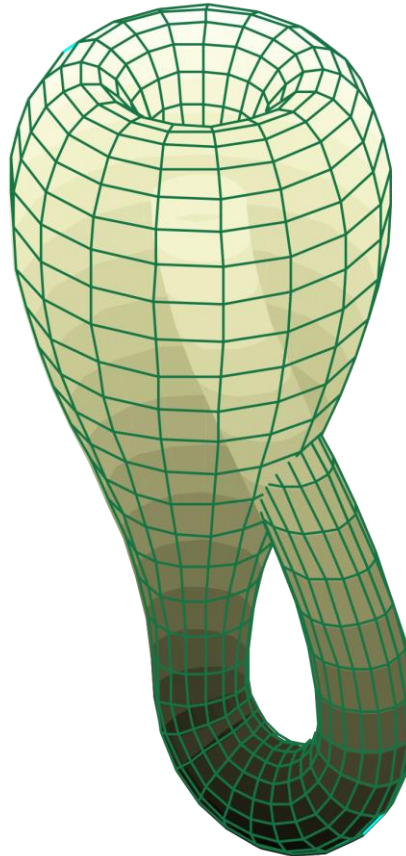
Backslides

- *Möbius* strip

Backslides

- ***Möbius* strip**: If its full length were crawled by an ant, the ant would return to its starting point having traversed both sides of the paper without ever crossing an edge.

→ Unorientable surface with boundaries

Backslides

- *Klein* bottle

Backslides

- *Klein* **bottle**: a one-sided surface which, if traveled upon, could be followed back to the point of origin while flipping the traveler upside down

- → Unorientable surface without boundaries