23 ICHST Budapest, July 29, 2009

SYMPOSIUM S-8

Ideas and Instruments in the development of physics:

From Atwood's Machine to Millikan's experiment of the photoelectric effect.

Arthur Stinner

SYMPOSIUM S-8

This symposium attempts to present in a new light important ideas and instruments in the history of physics that are a central part of physics teaching.

SYMPOSIUM S-8…

Beginning with Atwood's Machine in the 18th century to Millikan's *photoelectric effect* in the 20th century, we will touch on famous experiments and the associated basic ideas of classical physics to the emergence of quantum theory.

Atwood’s Machine

A. Stinner

First direct demonstration of Newton’ Laws of motion. A good example to illustrate the mathematization of physics.

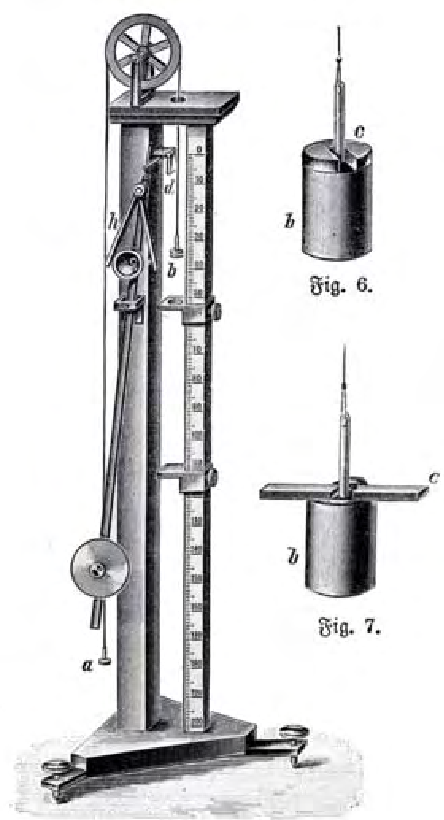


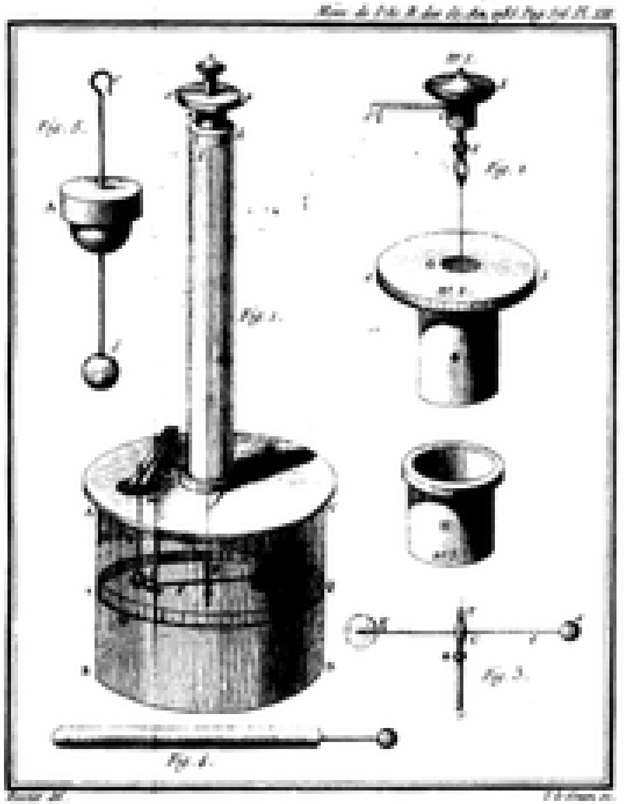
Fig. 5.
Atwoodsche Fallmaschine

Joule’s Electromagnetic Rotor

Joule’s Electromagnetic Rotor
and the Equivalence of
Mechanical and Heat Energy

G.Dragoni

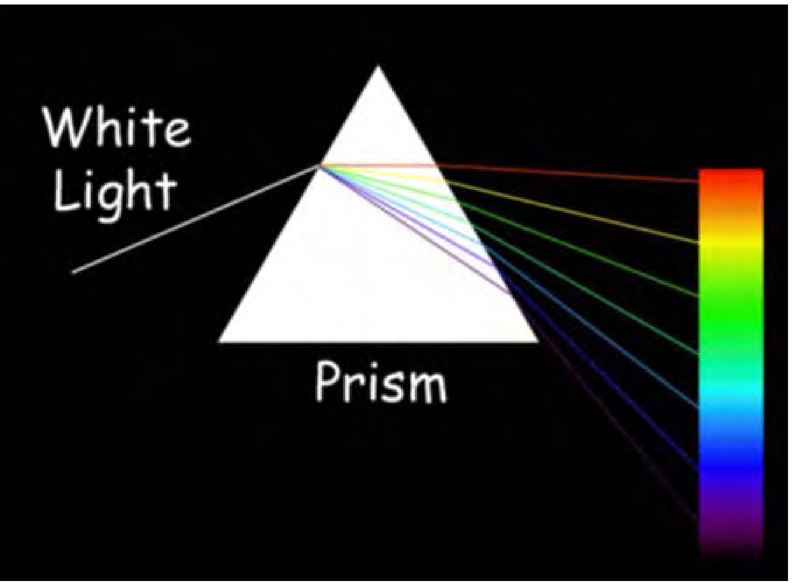
Coulomb’s apparatus and Weber's Electrodynamometer

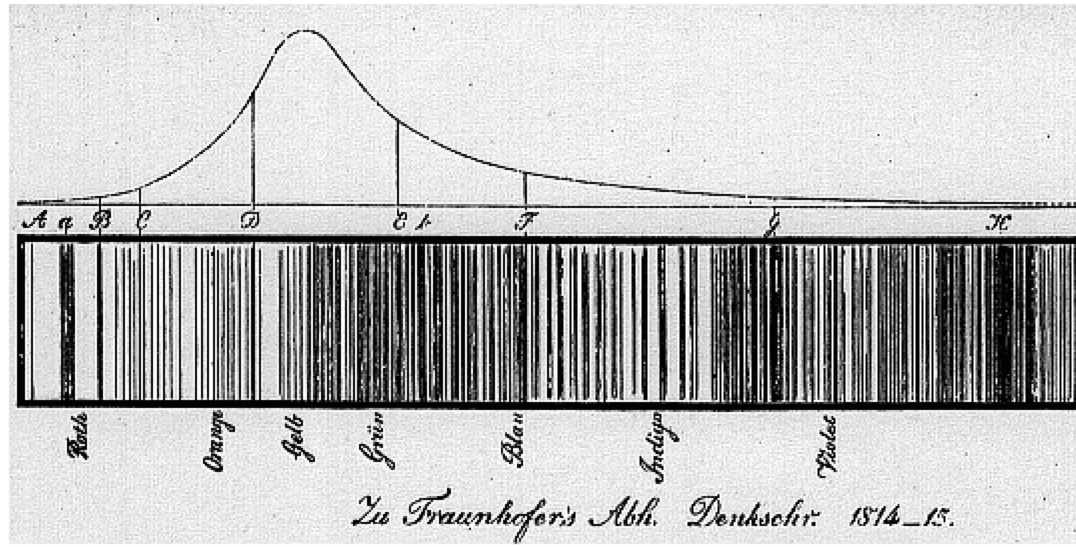


The changing meanings of precision, from Coulomb to Gauss and Weber.

S.Heinicke and P. Heering

Fraunhofer’s discovery of the dark lines of the solar spectrum





J. Teichmann

The Hero and the Dragon: Fraunhofer’s discovery of the ‘dark lines’ of the solar spectrum.

The Induction Coil

S. Jeszenszky: The induction coil and electromagnetic waves

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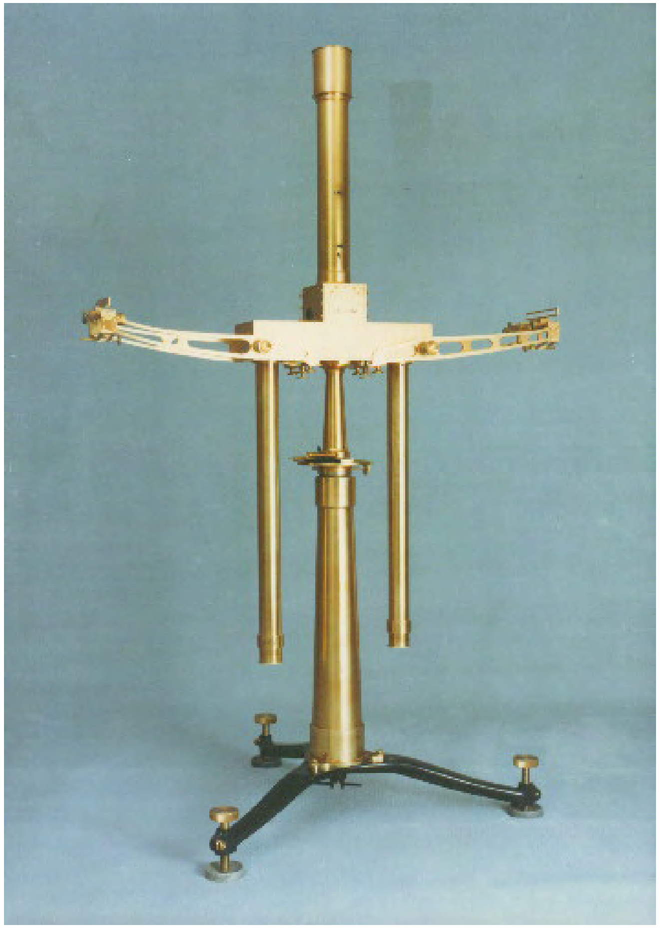
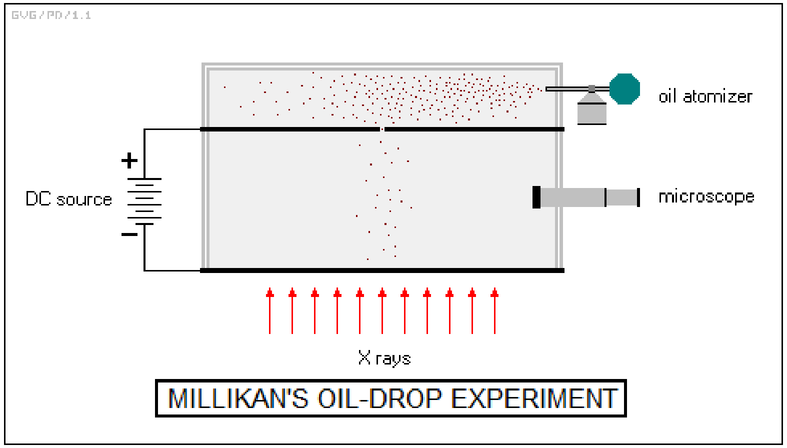
The Eötvös Apparatus

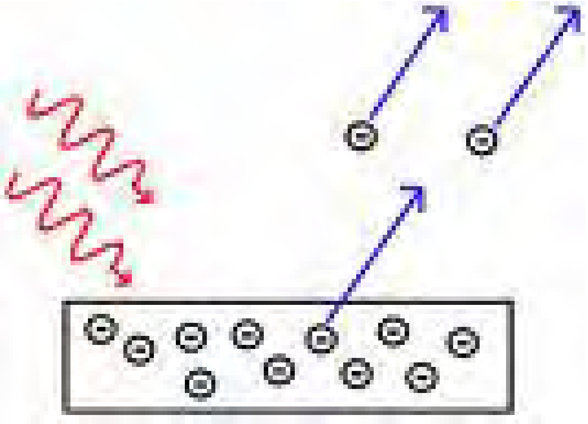
L. Kovács:

Determining the equivalence of inertial and gravitational mass.



The Photoelectric Effect





M. Niaz:
The experimental confirmation of Einstein's 'heuristic' to explain the photoelectric effect

SYMPOSIUM S-8…

Every one of the instruments and the concepts underlying the experiments are part of the general physics curriculum and discussed in textbooks.

However, most curricula avoid historical treatment, and textbook presentations of these instruments and the associated ideas are generally historically sparse, and lack a social context.

SYMPOSIUM S-8…

To make the teaching of science (physics) more vivid and interesting to the student, we are looking for ways to incorporate the history of science in more authentic ways.

Presentation I:

Atwood's Machine:

The experimental demonstration of Newtonian mechanics and the mathematization of the physics of mechanics.

Atwood's machine, a research instrument to study Newtonian physics, was invented in the 1780s.

One of the standard *exemplars* for elementary physics, featured in every textbook, is the study of the motion of two unequal weights attached to a pulley.

However, very few texts discuss the history of this exemplar. Students learn the algorithm for the solution of the motion of the weights and then proceed to solve standard textbook problems.

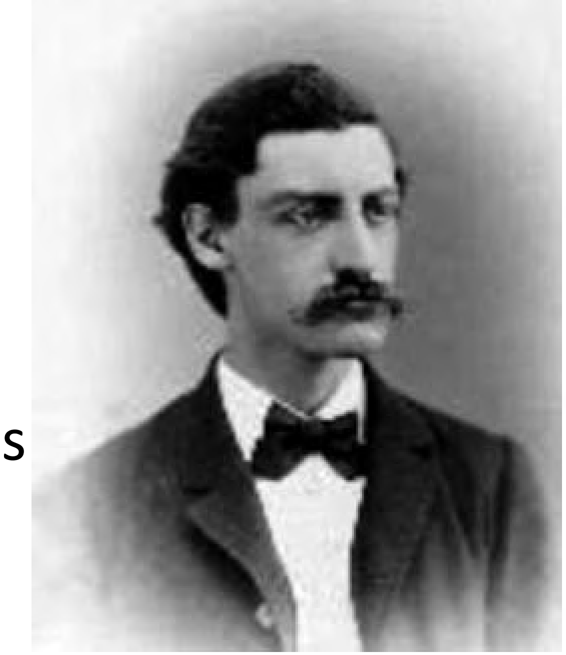
I will argue that it is possible to illustrate the mathematization of the physics of mechanics, starting with a thought experiment, followed by the standard application Newtonian physics, and ending with the Lagrangian reformulation of Newton’s laws.

All this will be placed in historical context.

George Atwood, FRS, was a popular lecturer at Cambridge.

In his book he described a series of twelve demonstrations to illustrate Newton's laws of motion, to be done with his apparatus.

He used a pendulum which ticked off the seconds, and adjusted the distances of fall to make the times of fall an integral numbers of seconds.



George Atwood
(1745-1807)

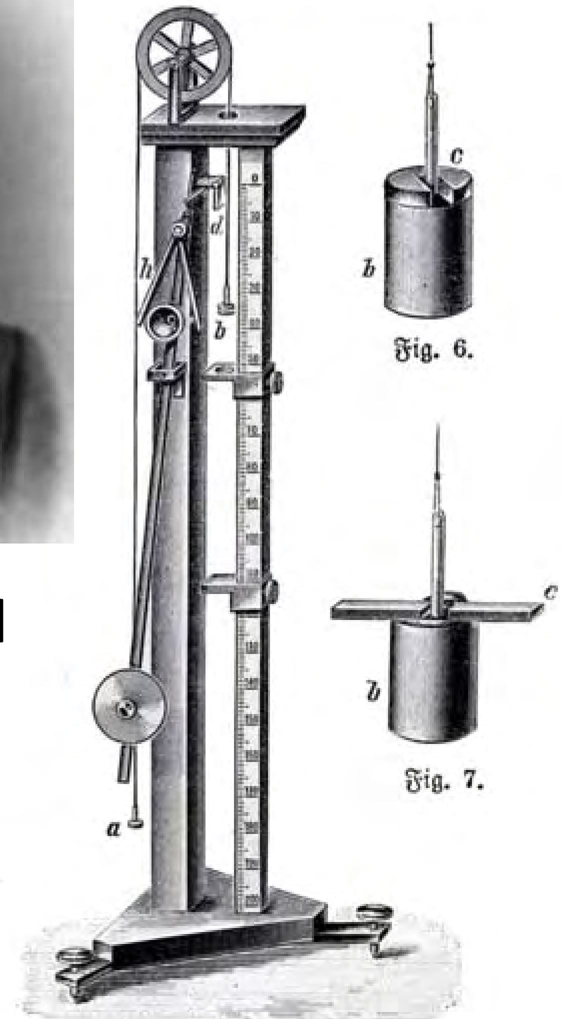
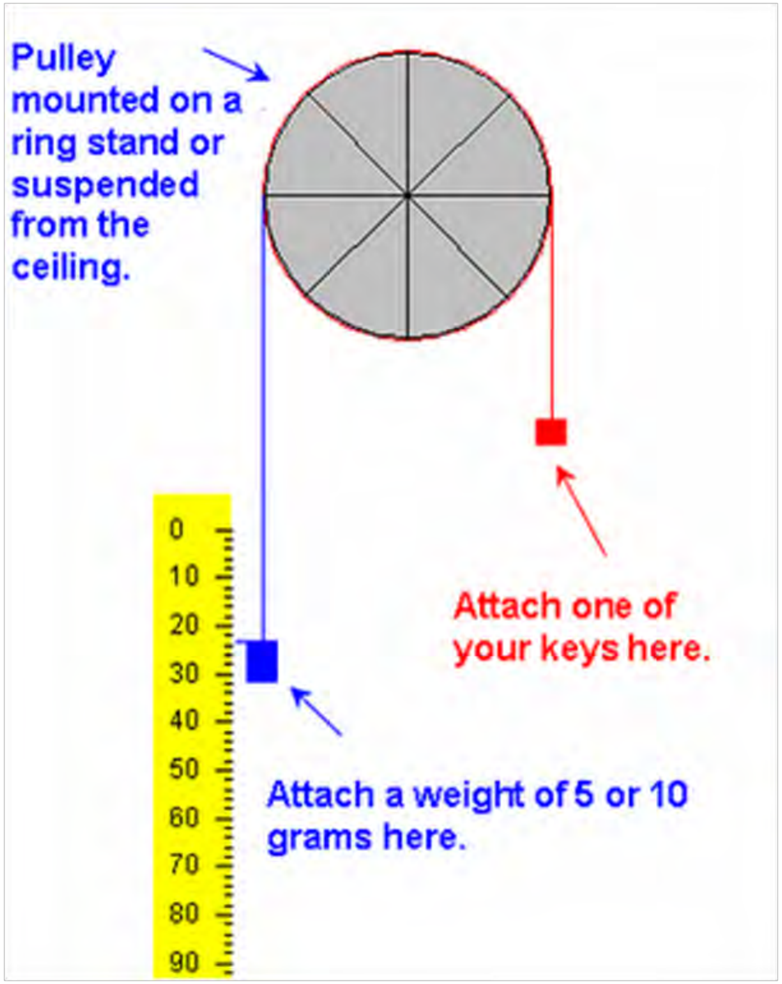
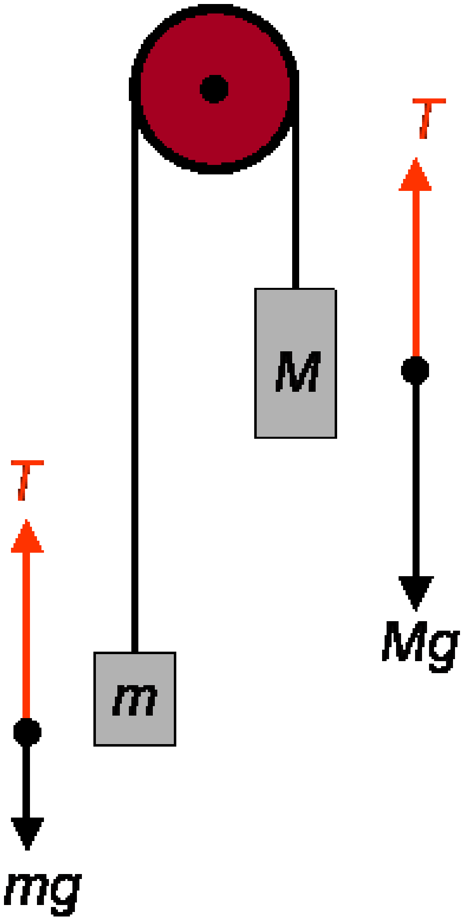


Fig. 5.
Atwoodsche Fallmaschine

The picture at the right shows West Point cadets using an Atwood's machine about 1900.

This instrument is the one shown here, currently on display at the National Museum of American History of the Smithsonian Institution.


Pulley mounted on a ring stand or suspended from the ceiling.
Attach one of your keys here.
Attach a weight of 5 or 10 grams here.
0
10
20
30
40
50
60
70
80
90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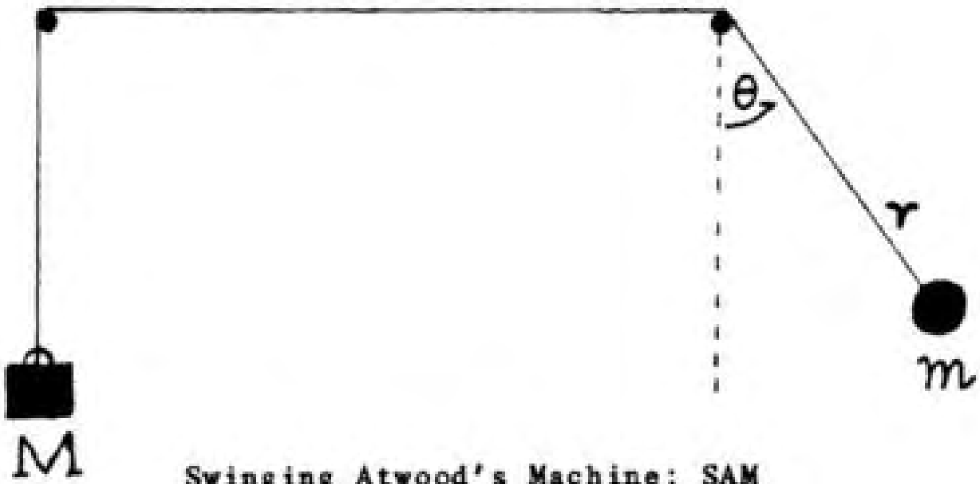
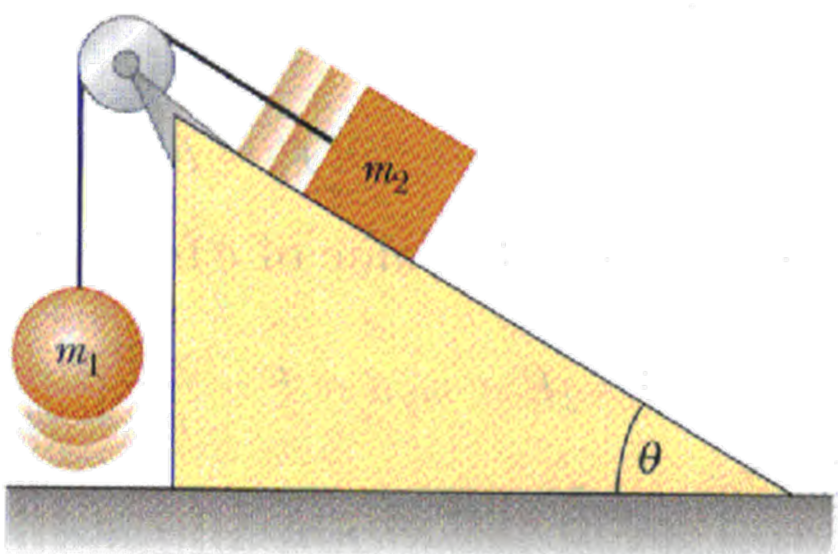
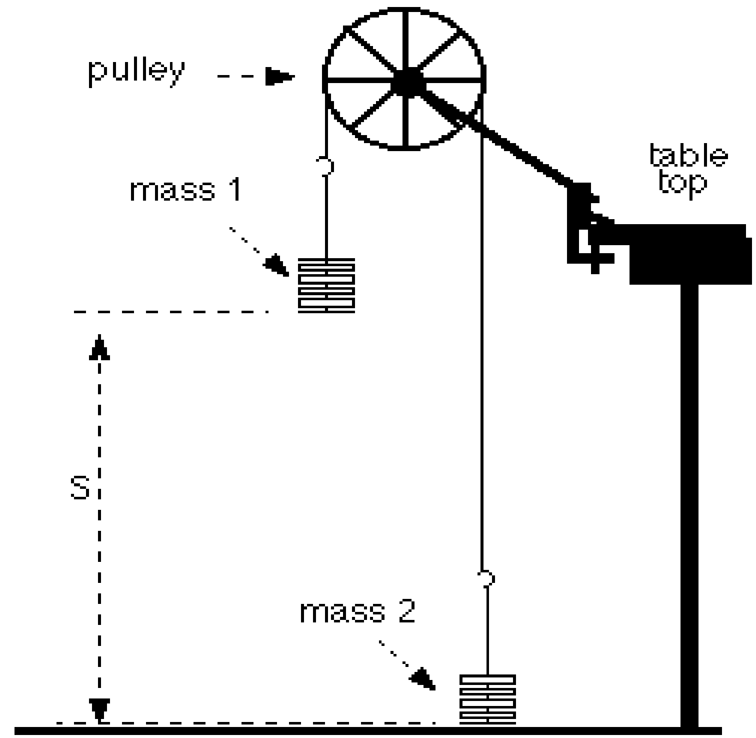


Swinging Atwood's Machine: SAM



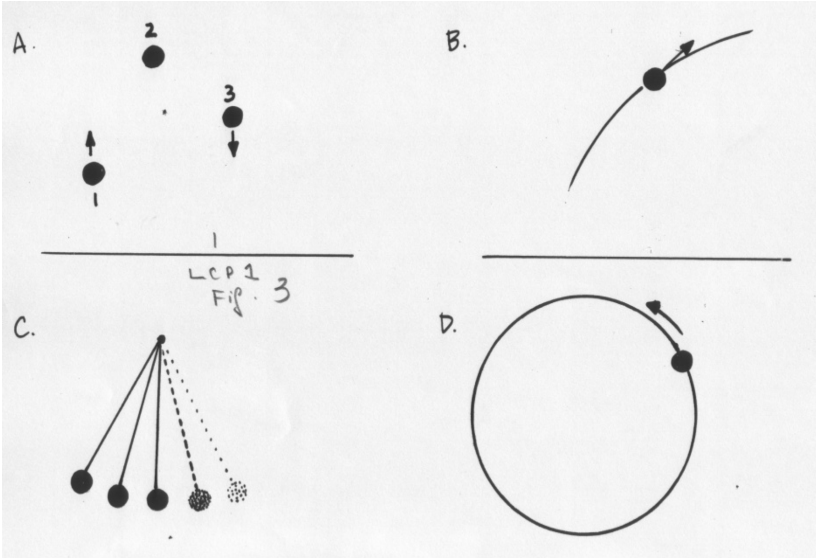


Aristotle

Aristotle distinguished between terrestrial and celestial motion.

He identified two types of motion on earth:

1. Natural
2. Violent



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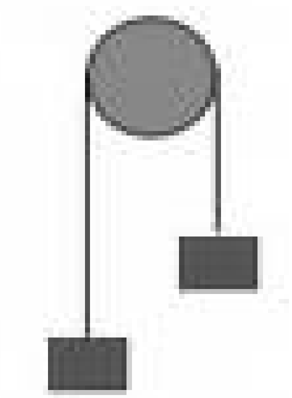


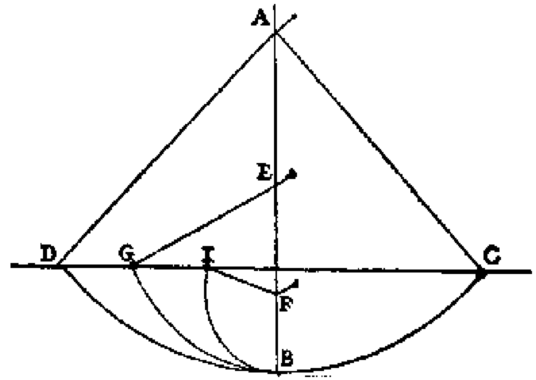
Aristotle:

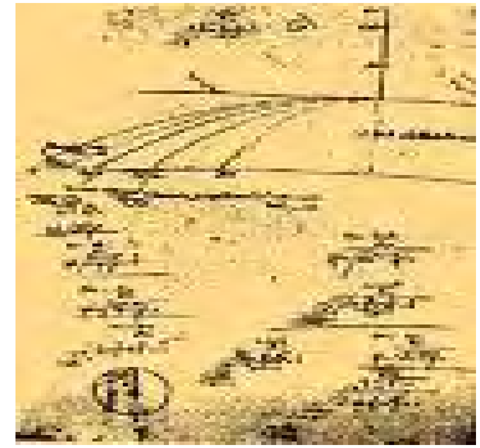
Aristotle was not looking for quantitative relationships and was only interested in classification, quality and potentiality.

A freely-falling object was an example of natural motion, a thrown javelin of violent motion.

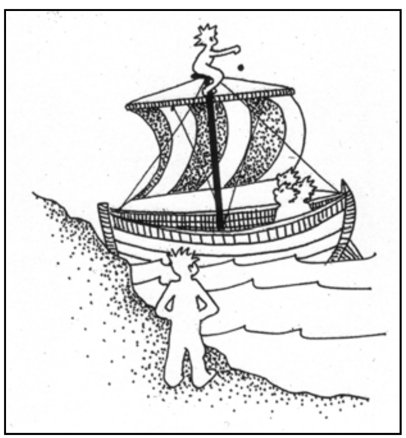
The motion of two unequal masses on a simple pulley would have probably been an example of a constrained natural motion.

Galileo…





Galileo studied motion using Euclidean geometry and Euclidean ratios. He investigated free fall, motion along an inclined plane, the period of a pendulum, and simple trajectory motion. He also anticipated Newton's first law of motion.



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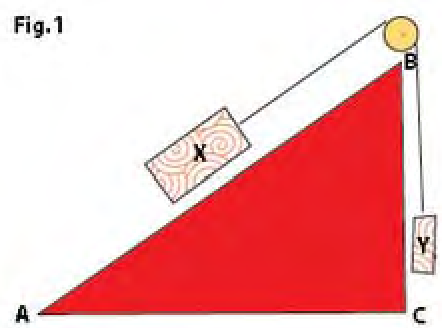

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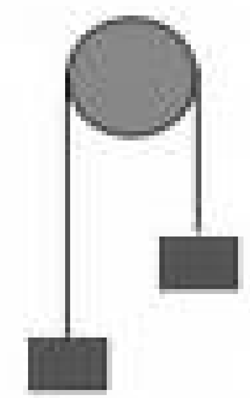
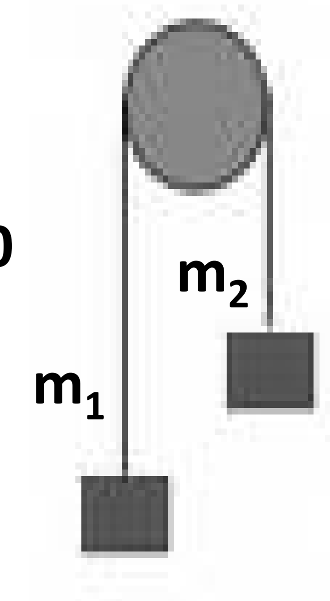


Galileo: Thought Experiment

A thought experiment Galileo could have devised to explain the motion of two unequal masses of an Atwood machine.

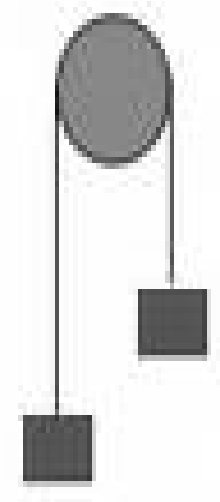
<u>Observations:</u>

1. When **$m_1 = m_2$,** there is no motion.
2. When **$m_1 > m_2$**, the acceleration is greater than **0** and less than **g**, the acceleration of free fall.
3. When **$m_1 >> m_2$**, the acceleration approaches **g**.



Galileo…

<u>Assumptions made</u>:



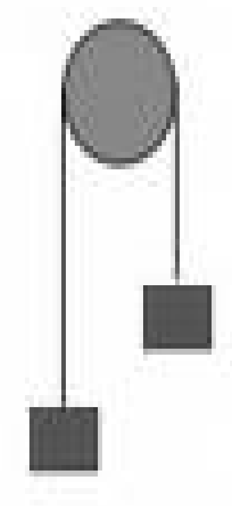
1. There is no friction and the mass of the pulley can be neglected.
2. The *effective force* is proportional to ($\mathbf{m_1 - m_2}$).
3. The mass of the total system to be accelerated is ($\mathbf{m_1 + m_2}$).
4. The mathematical expression that follows must be dimensionally correct.

Galileo…

<u>Hypothesis:</u>

The acceleration of the masses is directly proportional to $(m_1 - m_2)$ and inversely to $(m_1 + m_2)$, or

$$\mathbf{a = \{(m_1 - m_2) / (m_1 + m_2)\}\, g}$$



Note: This expression satisfies all conditions above.

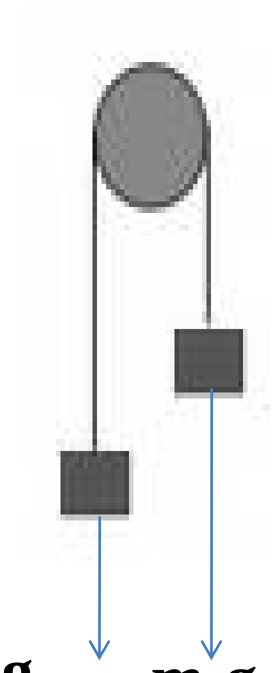
Newton’ solution

Using Newton’s second law of motion, the effective force F is:

$$(m_1 - m_2)g$$

The total mass of the accelerating system is:

$$(m_1 - m_2)g$$



Since **F = ma,** it follows that

$$\mathbf{a = \{(m_1 - m_2) / (m_1 + m_2)\} g}$$

Lagrange recasts Newton’s second law

In 1780’s Lagrange reformulated Newton’s second law.

He developed a differential equation that banished the notion of force, using a combination of kinetic and potential energies.

$$\mathbf{d/dt\ (\delta L/\ \delta V) - \delta L/\ \delta y = 0}$$

where

$$\mathbf{L = T - V}$$

L = The “Lagrangian”, **T** = Kinetic energy and **V**= Potential energy

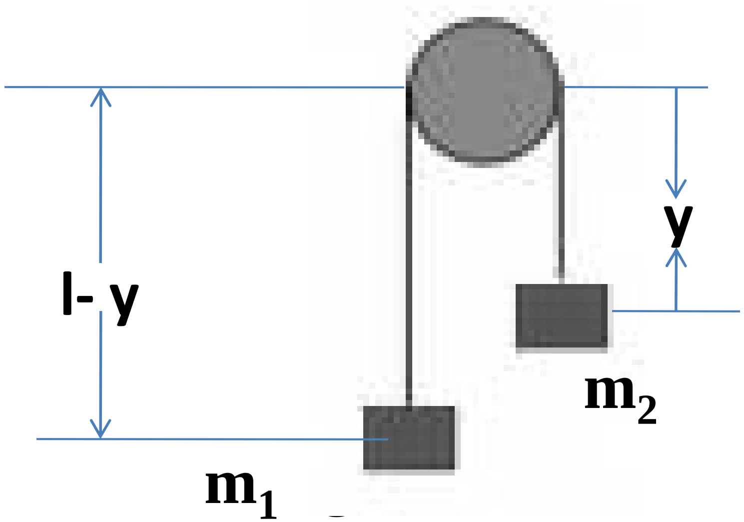
(**V** = velocity **Y** = position)

Lagrange's solution

$$T = \tfrac{1}{2} m_1 v^2 + \tfrac{1}{2} m_2 v^2$$

and

$$V = -\{m_1 g y + m_2 g(l-y)\}$$



Lagrange

Using a powerful mathematical approach to solve a relatively simple problem:

$$\mathbf{d/dt\ (\delta L/\ \delta v) - \delta L/\ \delta y = 0}$$

where $\mathbf{L = T - V}$

$$\mathbf{T = \tfrac{1}{2} m_1 v^2 + \tfrac{1}{2} m_2 v^2}$$

and $\mathbf{V = -\{m_1 g y + m_2 g(l-y)\}}$

Lagrange

$$d/dt\ (\delta L/\ \delta v) - \delta L/\ \delta y = 0$$

$$L = \tfrac{1}{2}(\ m_1 + m_2\ )\ v^2 + m_1 g y + m_2 g(l - y)$$

Therefore: $$d/dt\ \{(\ m_1 + m_2)\ v\} - (m_1 - m_2)g = 0$$

or $$(m_1 + m_2)\ a = (m_1 - m_2)g$$

therefore: $$a = (m_1 - m_2)g\ /\ (m_1 + m_2)$$

This is the same result as the one obtained using Newton's second law.

Example : The motion of a planet

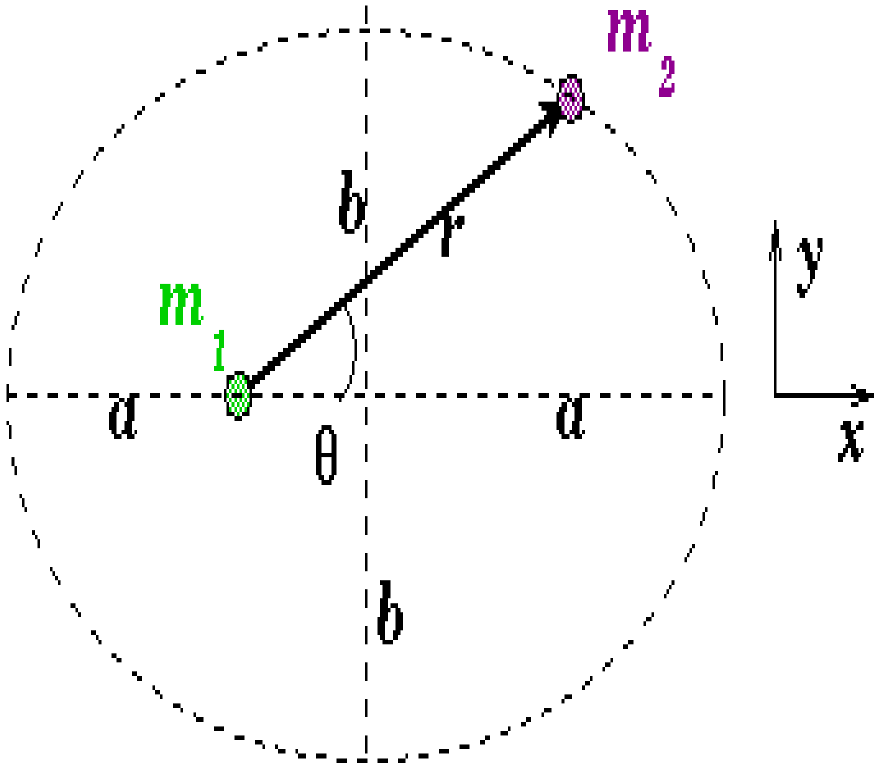
$T = 1/mv^2 + 1/mr^2 \, (d\theta/dt)^2$

$V = -(GMm)/r$

$d/dt(m\,dr/dt) - mr \, (d\theta/dt)^2 + GMm/r^2 = 0$

and

$d/dt\{mr^2 \, (d\theta/dt)\} = 0$



Conclusion

1. After Lagrange

2. Implications for teaching physics