www.eotvos100.hu

100th anniversary of Roland Eötvös (1848-1919), physicist, geophysicist, and innovator of higher education
Commemorated in association with UNESCO

Eötvös Loránd (1848-1919) fizikus, geofizikus és a felsőoktatás megújítójának 100. évfordulója
Az UNESCO-val közösen emlékezve

United Nations Educational, Scientific and Cultural Organization

Egyesült Nemzetek Nevelésügyi, Tudományos és Kulturális Szervezete

Lajos Völgyesi

Szondy Gy., Tóth Gy., Kiss B., Fenyvesi E., Péter G., Somlai L., Égető Cs., Deák L., Barnaföldi G., Gróf Gy,. Harangozó P., Lévai P., Ván P.

Torsion Balance and Remeasurement of the Eötvös experiment

FFK-2019

Tihany, June 10-14. 2019.

United Nations
Educational, Scientific and
Cultural Organization

100th anniversary of Roland Eötvös (1848-1919), physicist, geophysicist, and innovator of higher education
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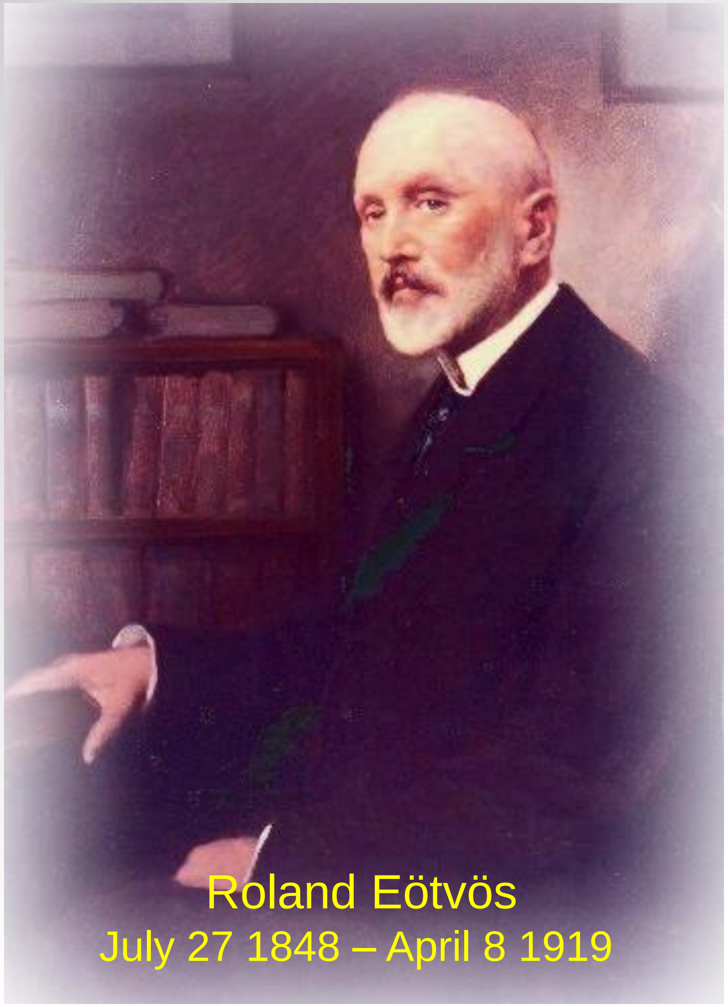
- Roland Eötvös was born in 1848 and died in 1919 so we celebrate the 100th anniversary of his death this year.
- United Nations Educational, Scientific and Cultural Organization (UNESCO) declared the year 2019 as “Eötvös year”.
- In 2017 we decided to celebrate this anniversary, by re-measure the Eötvös experiment for validating the equivalence of gravitational and inertial mass.
- When we started to study descriptions of the previous measurements, we found a possible explanation for the known systematic error and from this moment our plan of re-measurement became realy serious.
- Eötvös became a world famous physicist by his torsion balance. In the next we will discuss the base principle and short history of the torsion balance and then the preparations and present status of our new equivalence experiment.



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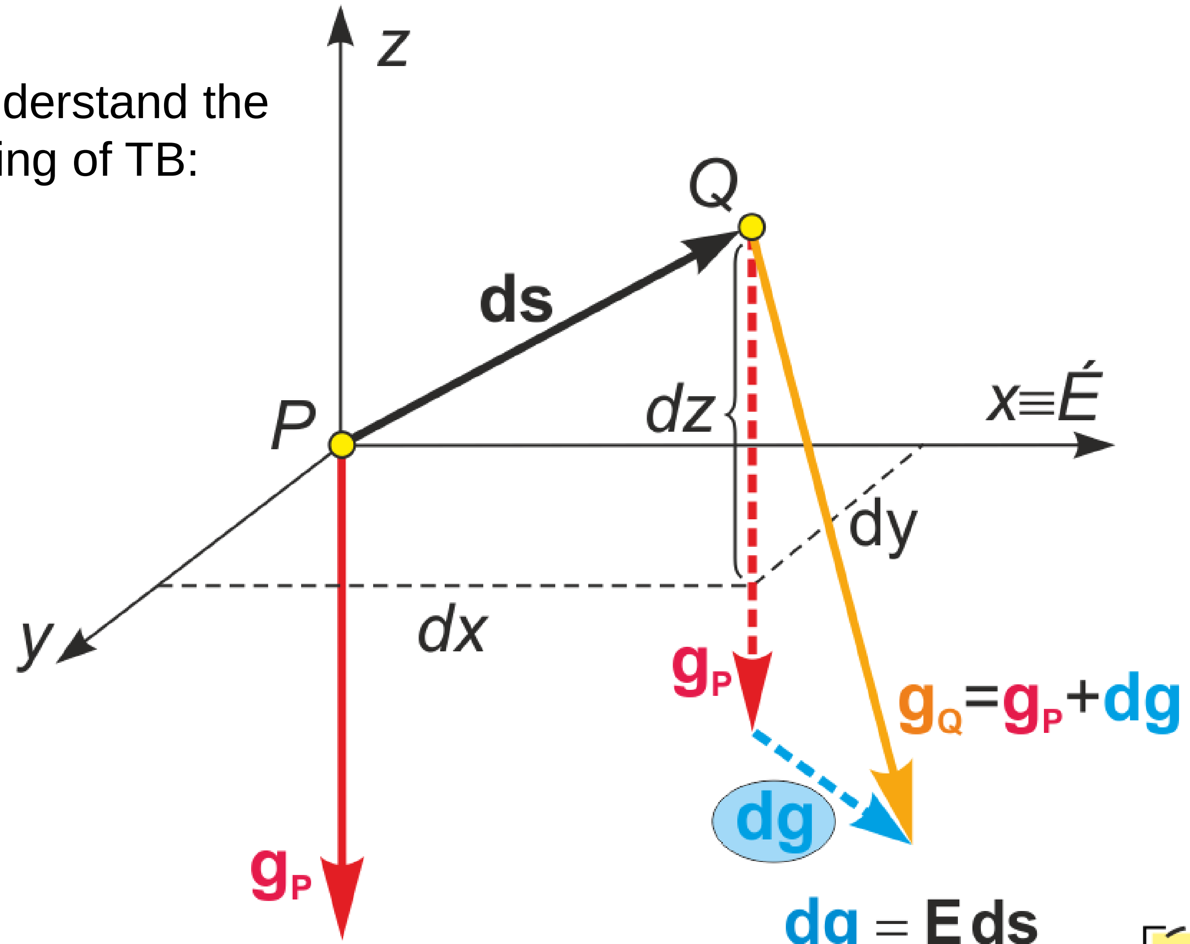
for to understand the functioning of TB:



$$\mathbf{dg} = \mathbf{E}\,\mathbf{ds}$$

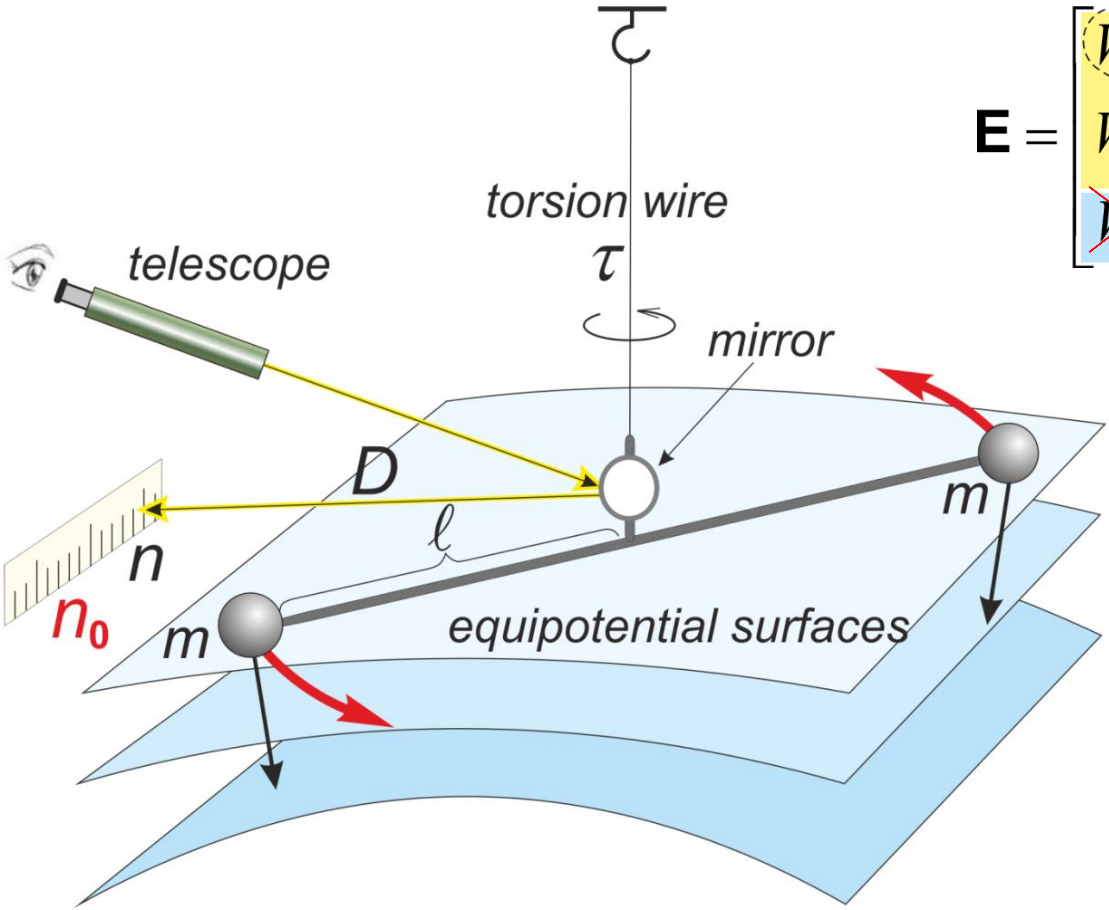
$$\mathbf{E} = \begin{bmatrix} W_{xx} & W_{xy} & W_{xz} \\ W_{yx} & W_{yy} & W_{yz} \\ W_{zx} & W_{zy} & W_{zz} \end{bmatrix}$$

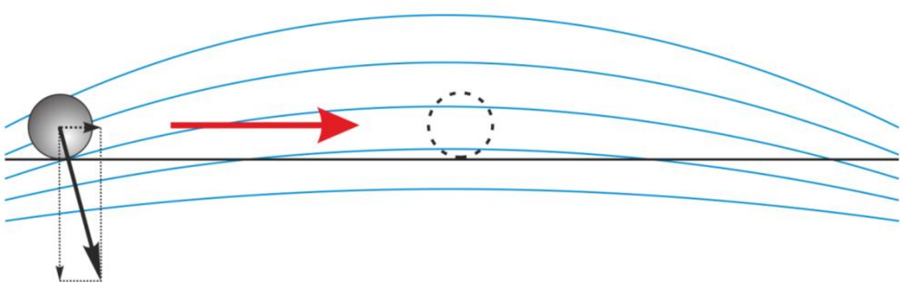
$$(W_{\Delta} = W_{yy} - W_{xx})$$

From torsion balance measurements:

W_{Δ}, W_{xy} W_{zx}, W_{zy}

$$\mathbf{E} = \begin{bmatrix} W_{xx} & W_{xy} & \cancel{W_{xz}} \\ W_{yx} & W_{yy} & \cancel{W_{yz}} \\ \cancel{W_{zx}} & \cancel{W_{zy}} & \cancel{W_{zz}} \end{bmatrix}$$

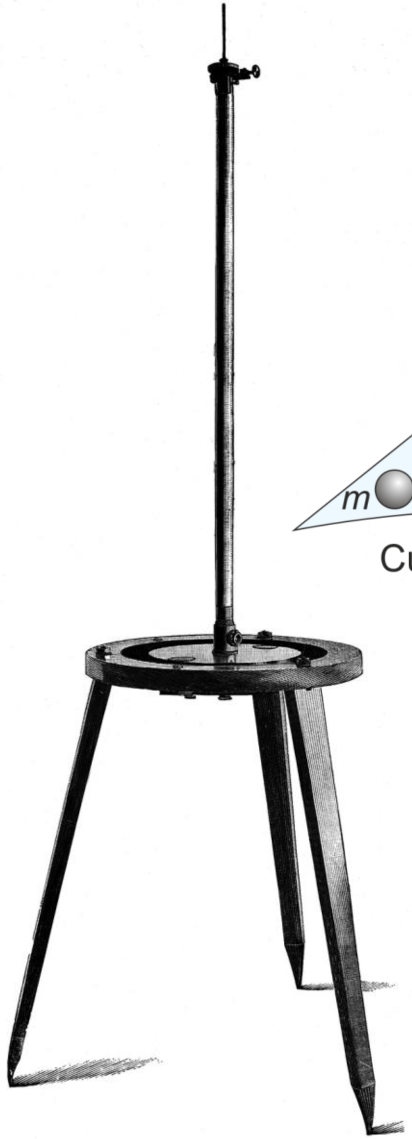


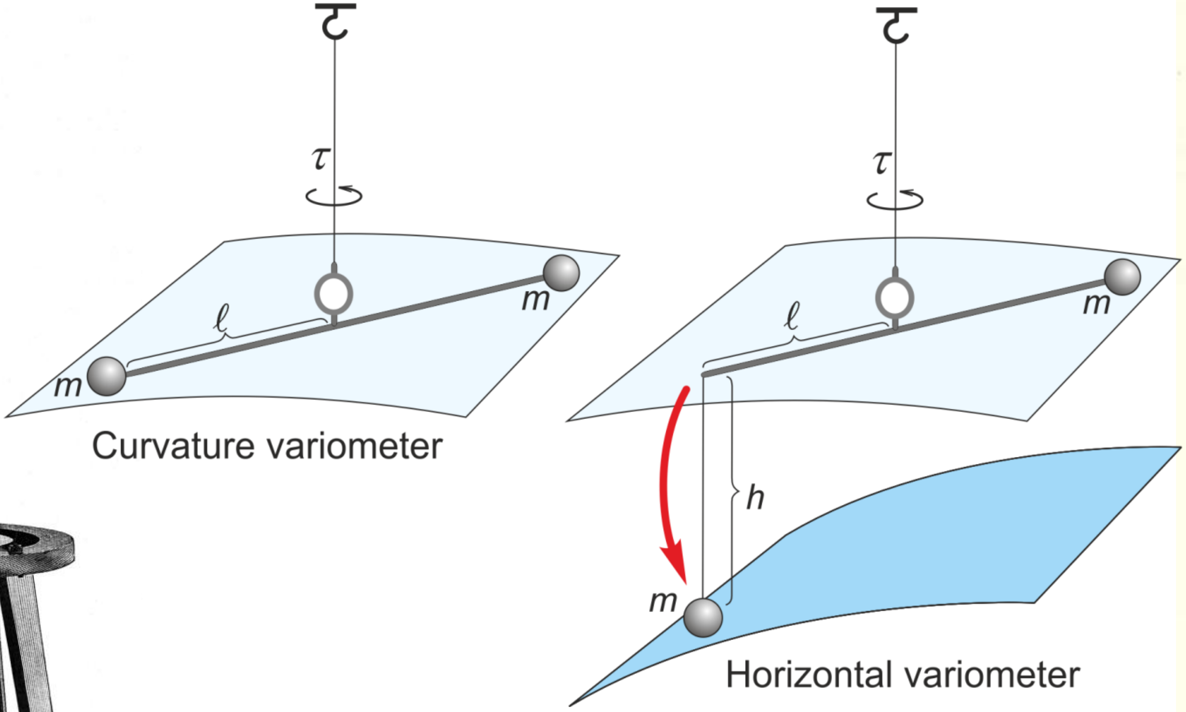


(spherical symmetry ⟶ torsion-free damped position n_0)

Curvature variometer was the classic Coulomb (Cavendish) balance, comprising a horizontal beam with two identical masses at each end, suspended on a torsion wire.

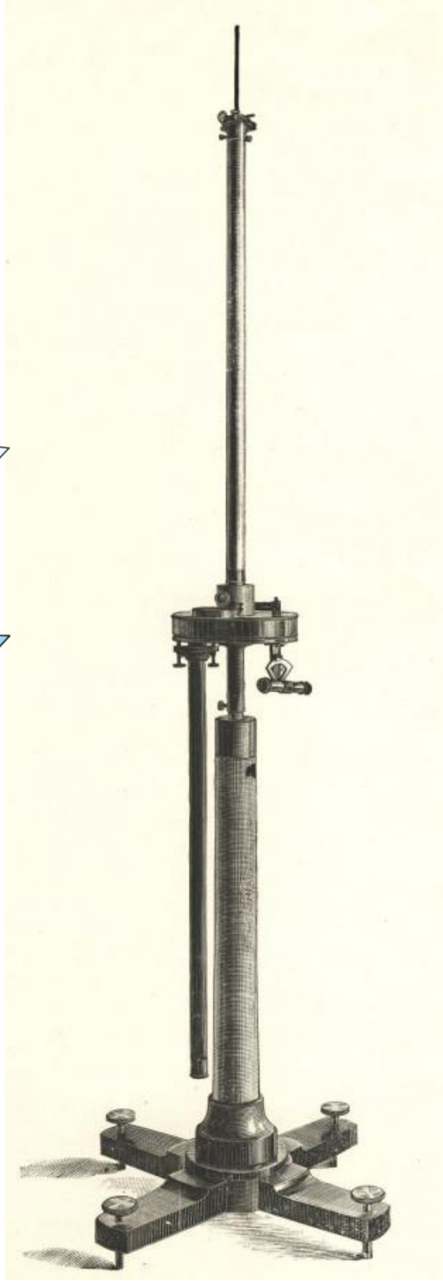
If the equipotential surface deviates from a sphere there are small horizontal forces turning the beam into direction of the smallest curvature, namely this balance can measure the degree of deviation of the equipotential surface from the spherical shape.





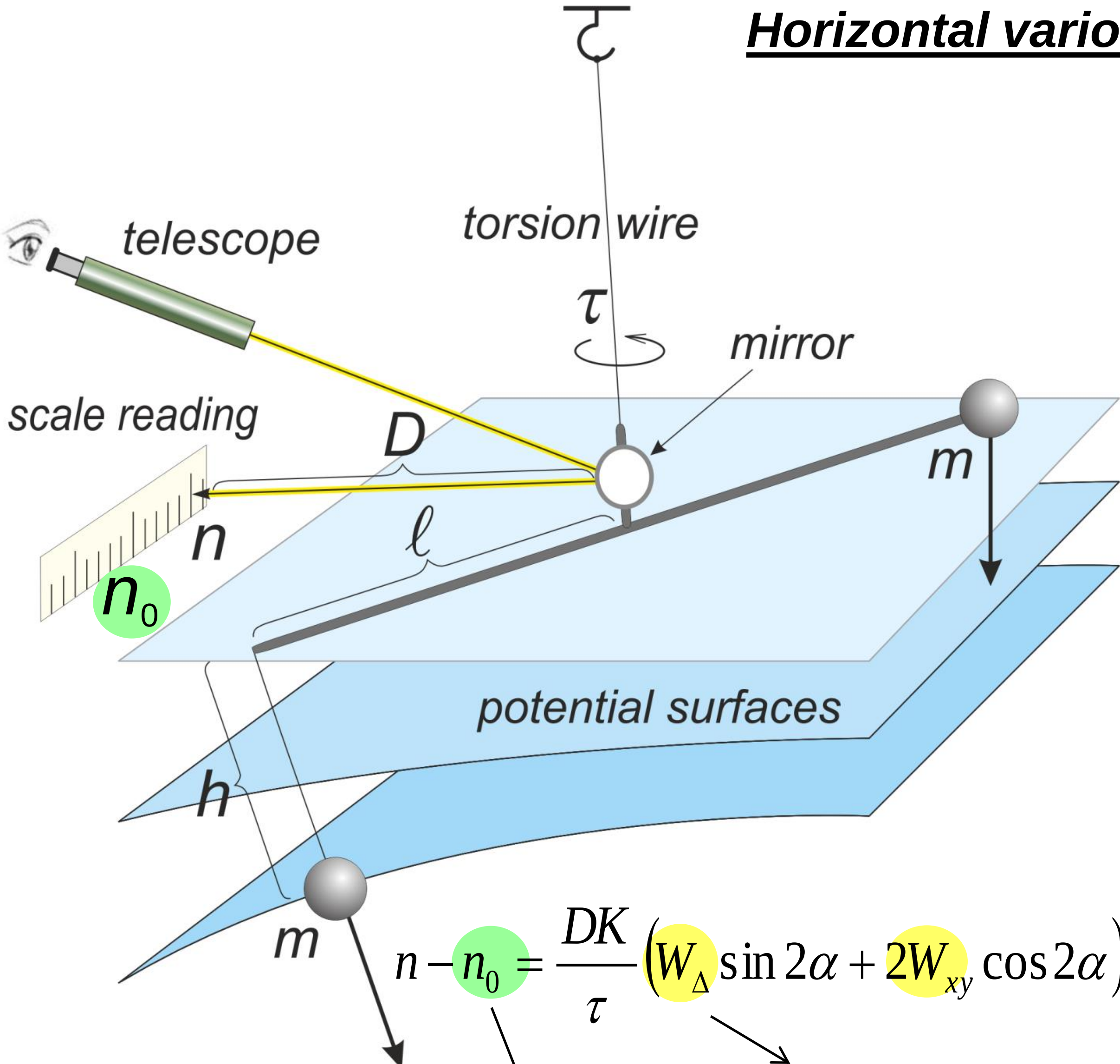
The great invention of Eötvös was that he took one of the masses off the beam and suspended it with a thin wire in a deeper position.

Curvature variometer
Eötvös (1890)



Horizontal variometer
Eötvös (1890)

Horizontal variometer

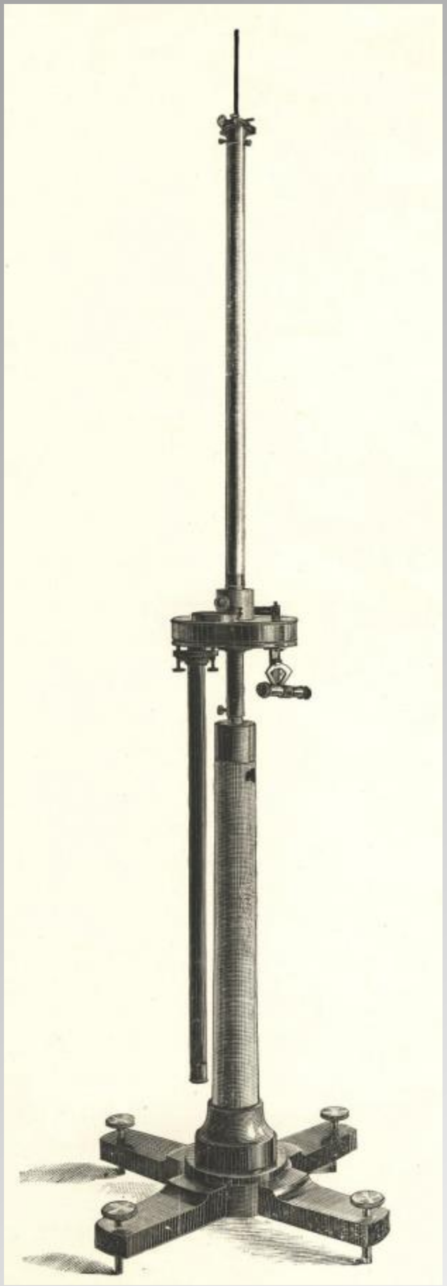


$$\mathbf{E} = \begin{bmatrix} W_{xx} & W_{xy} & W_{xz} \\ W_{yx} & W_{yy} & W_{yz} \\ W_{zx} & W_{zy} & \cancel{W_{zz}} \end{bmatrix}$$

$$n - n_0 = \frac{DK}{\tau}\left(W_\Delta \sin 2\alpha + 2W_{xy} \cos 2\alpha\right) + \frac{2Dhlm}{\tau}\left(W_{zy} \cos\alpha - W_{zx} \sin\alpha\right)$$

$$W_\Delta = W_{yy} - W_{xx}$$

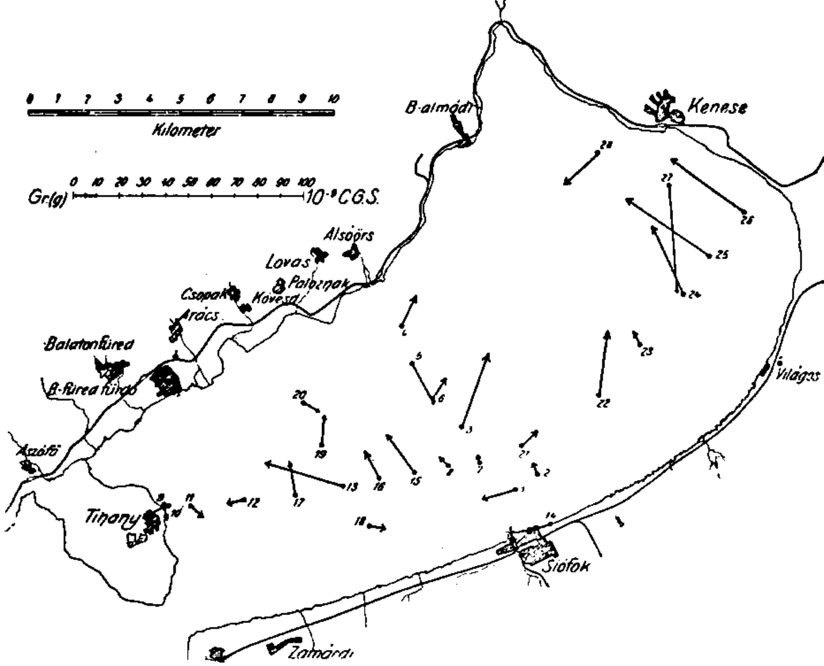
torsion-free position

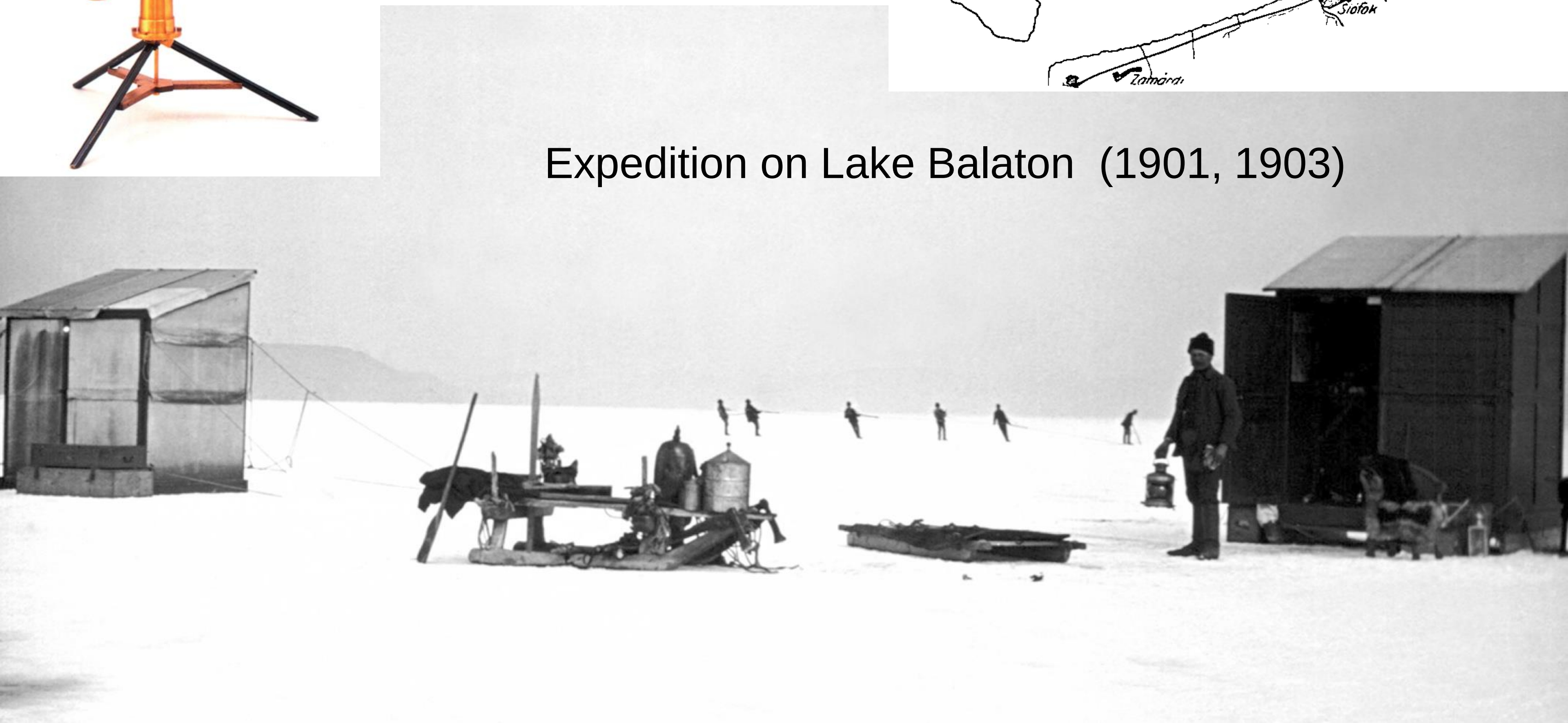


First Eötvös torsion balance:
Horizontal variometer, 1890

First field measurement: Ság-hill survey, 1891.

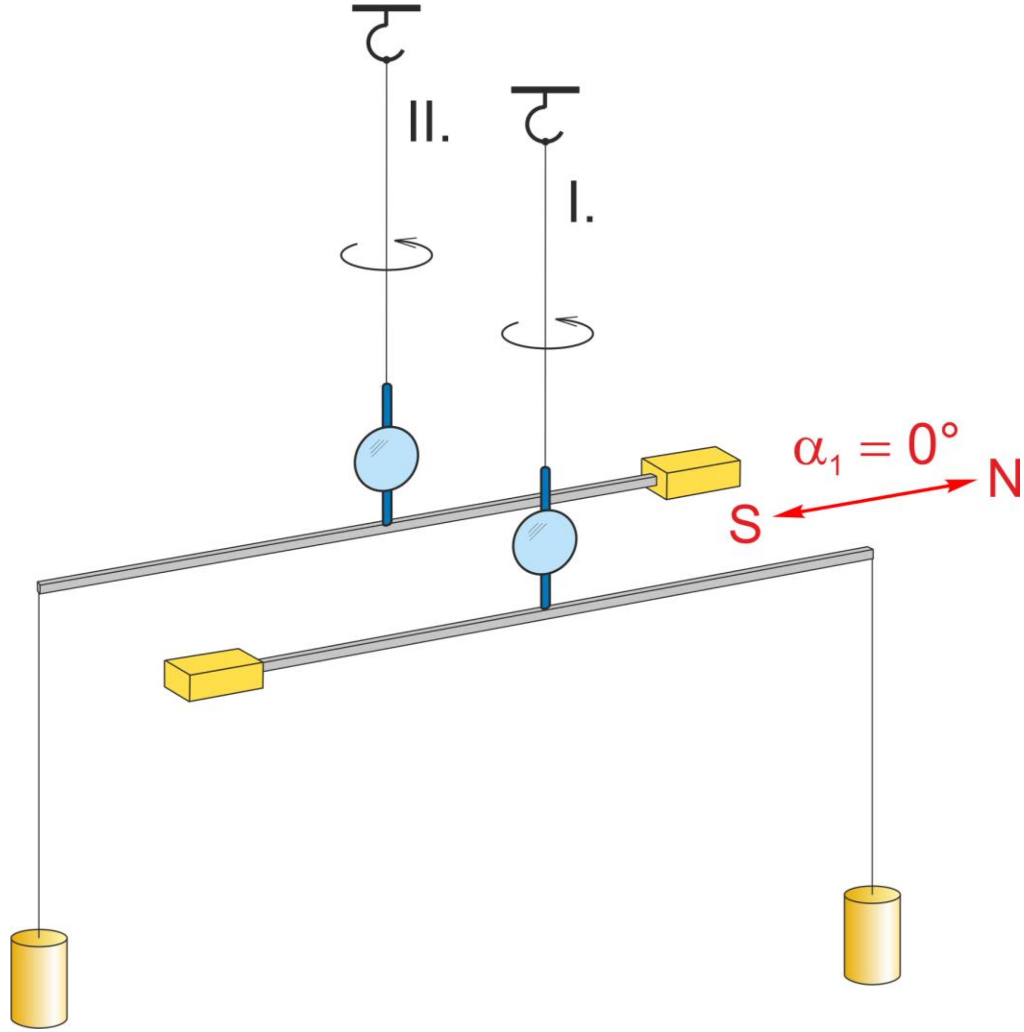
Balaton-balance (1898)





Expedition on Lake Balaton (1901, 1903)

“*Large double balance*” (1902)



$$n_1 - n_0 = \frac{DK}{\tau}\left(W_\Delta \sin 2\alpha + 2W_{xy}\cos 2\alpha\right) + \frac{2Dhlm}{\tau}\left(W_{zy}\cos\alpha - W_{zx}\sin\alpha\right)$$

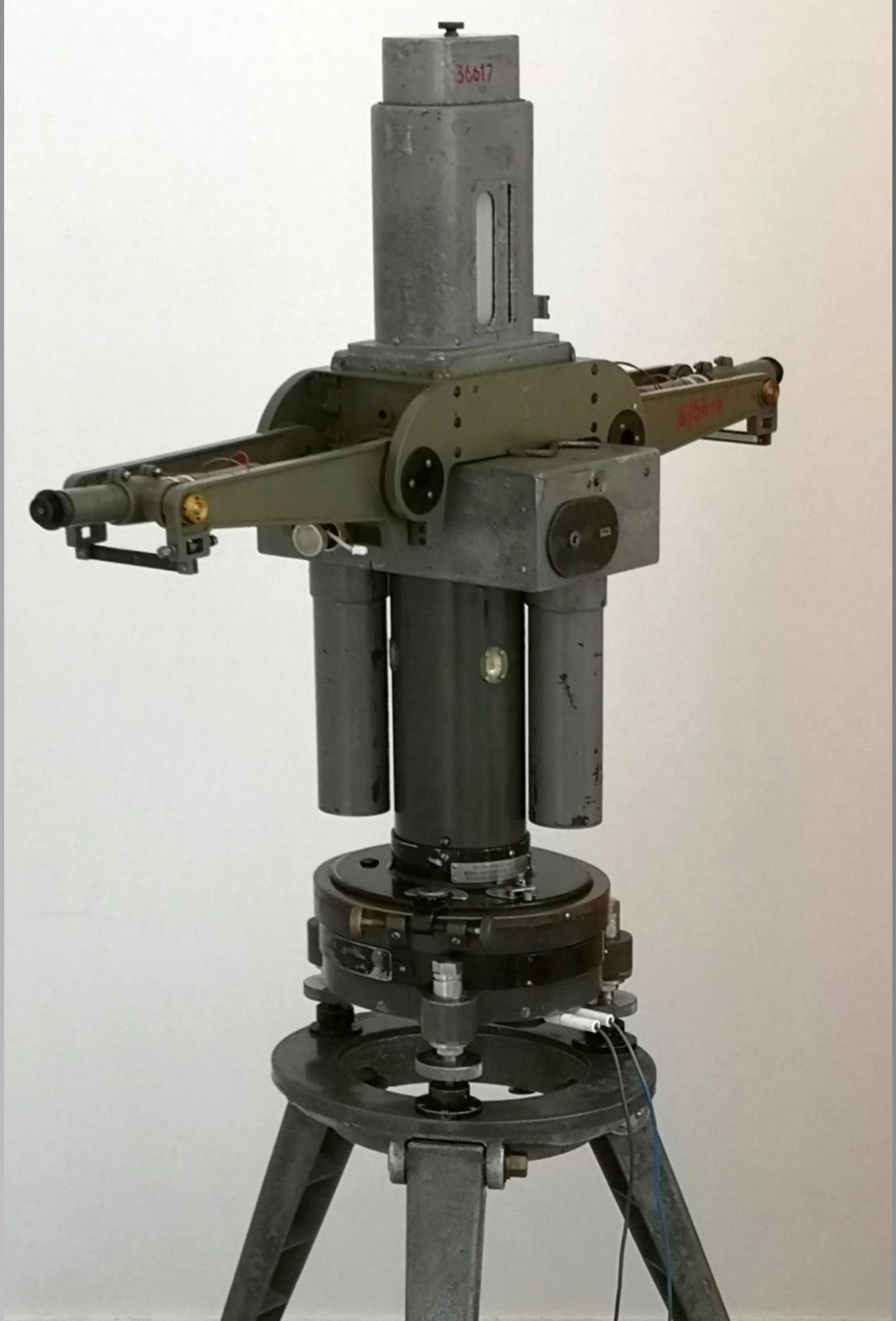
$$n_2 - n_0^* = \frac{DK}{\tau}\left(W_\Delta \sin 2\alpha + 2W_{xy}\cos 2\alpha\right) + \frac{2Dhlm}{\tau}\left(W_{zy}\cos\alpha - W_{zx}\sin\alpha\right)$$

Eötvös-Pekár Balance
(*Small Double Balance*)
1926, 1928, 1930

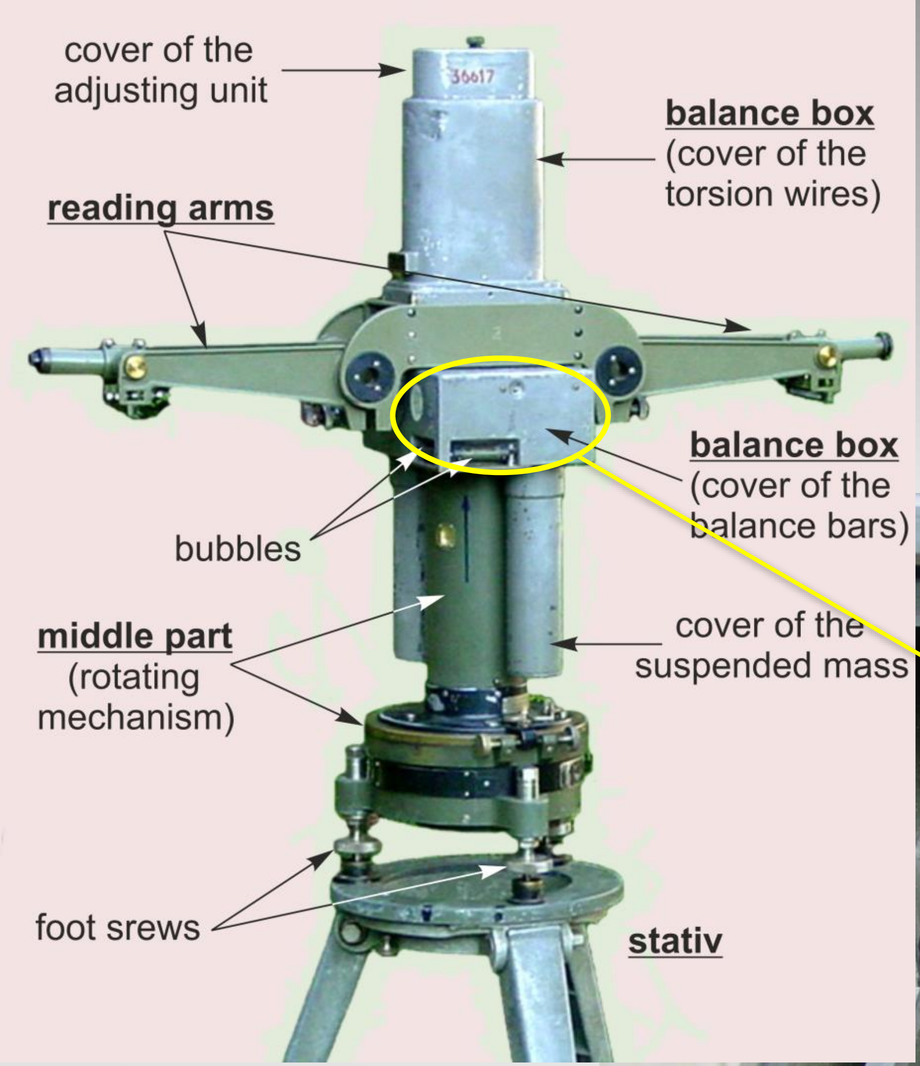
successful for field measurements,
non-automatic operation,
very accurate and reliable,
easily replaceable masses,
best usable for equivalence measurements

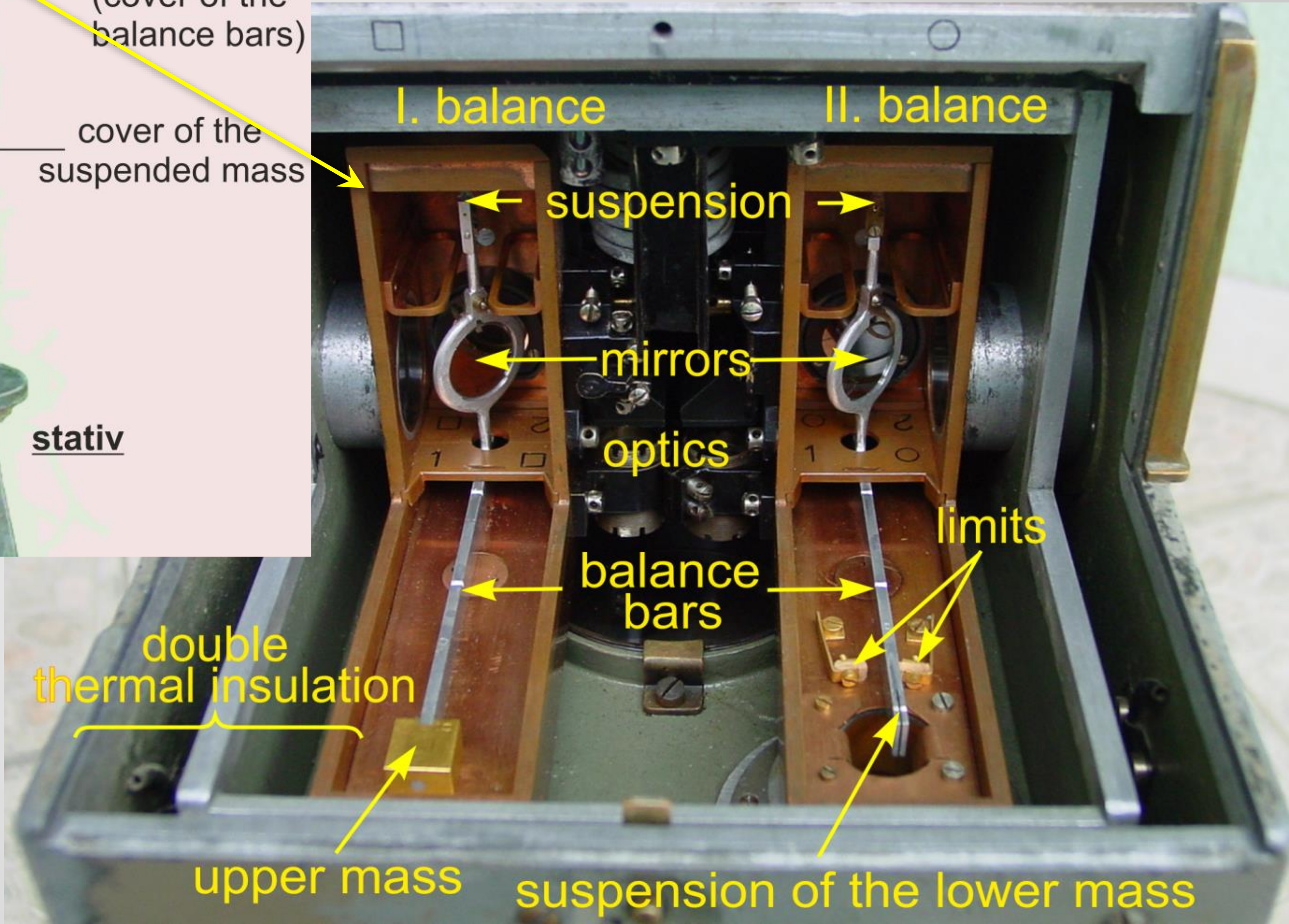
Eötvös-Rybár Balance
(*AutERBal Balance*)
1928

successful for field measurements,
automatic operation with photo registration,
not so accurate and reliable,
difficult to replace the masses,
hard to use for equivalence measurements



Look inside the torsion balance

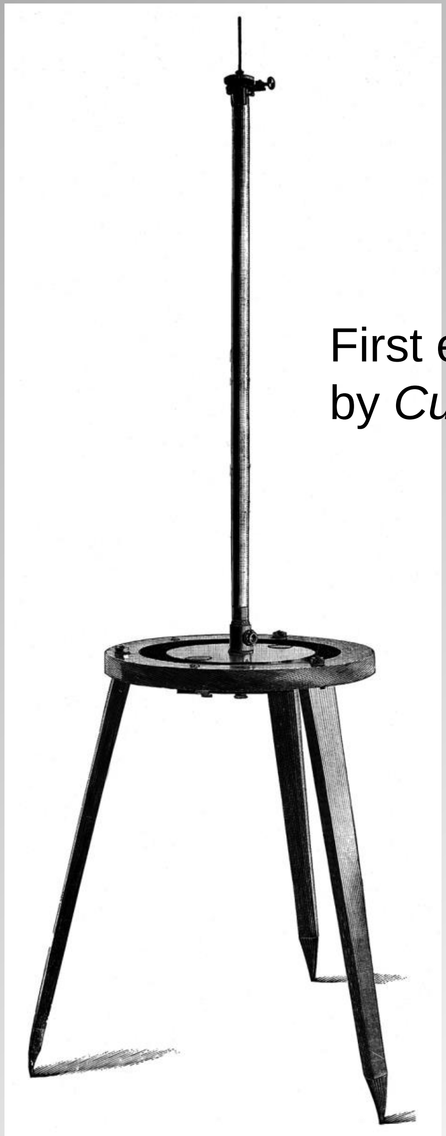




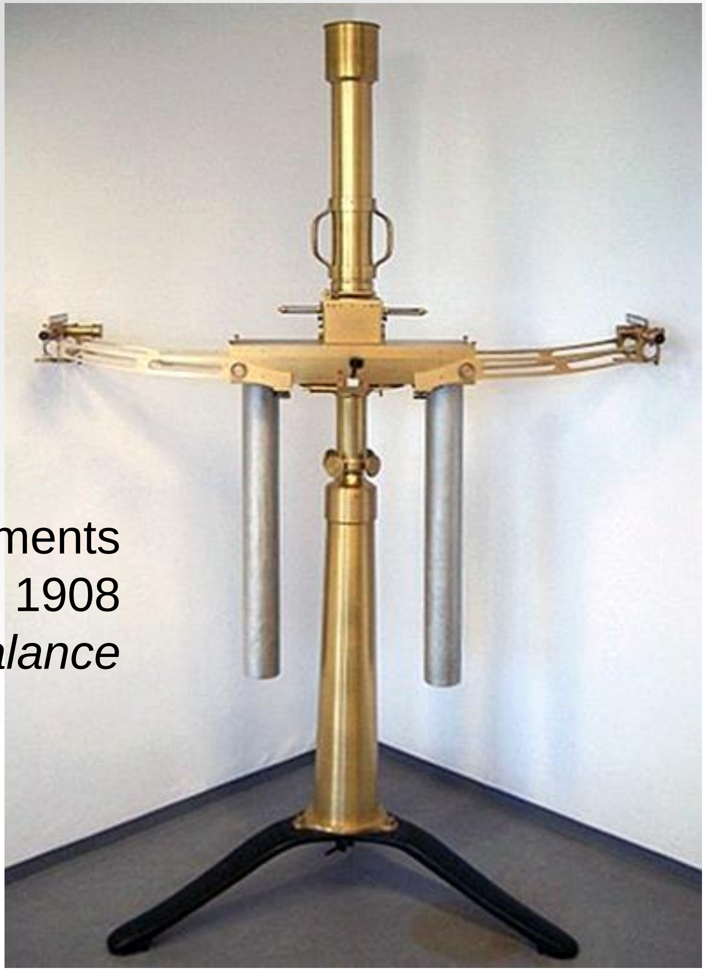

E54 (1954)
well suitable for field measurements

Equivalence principle

The Eötvös experiment

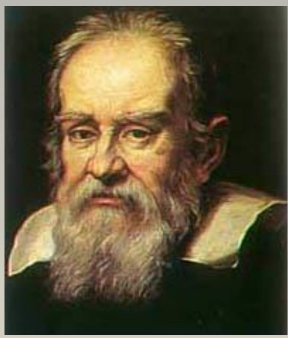


First experiment in 1896
by *Curvature Variometer*



EPF measurements
between 1906 and 1908
by *Large Double Balance*

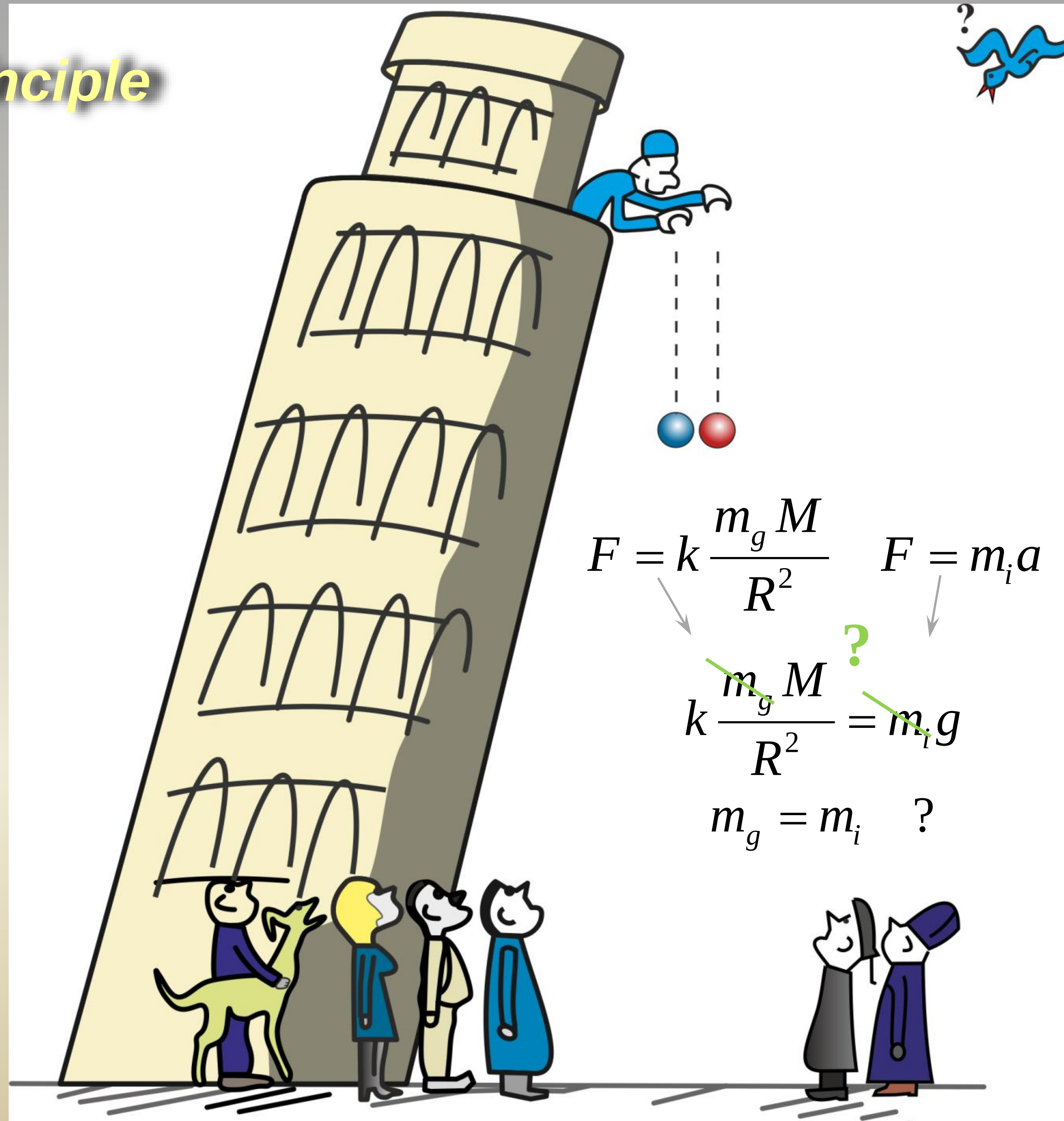
Equivalence principle

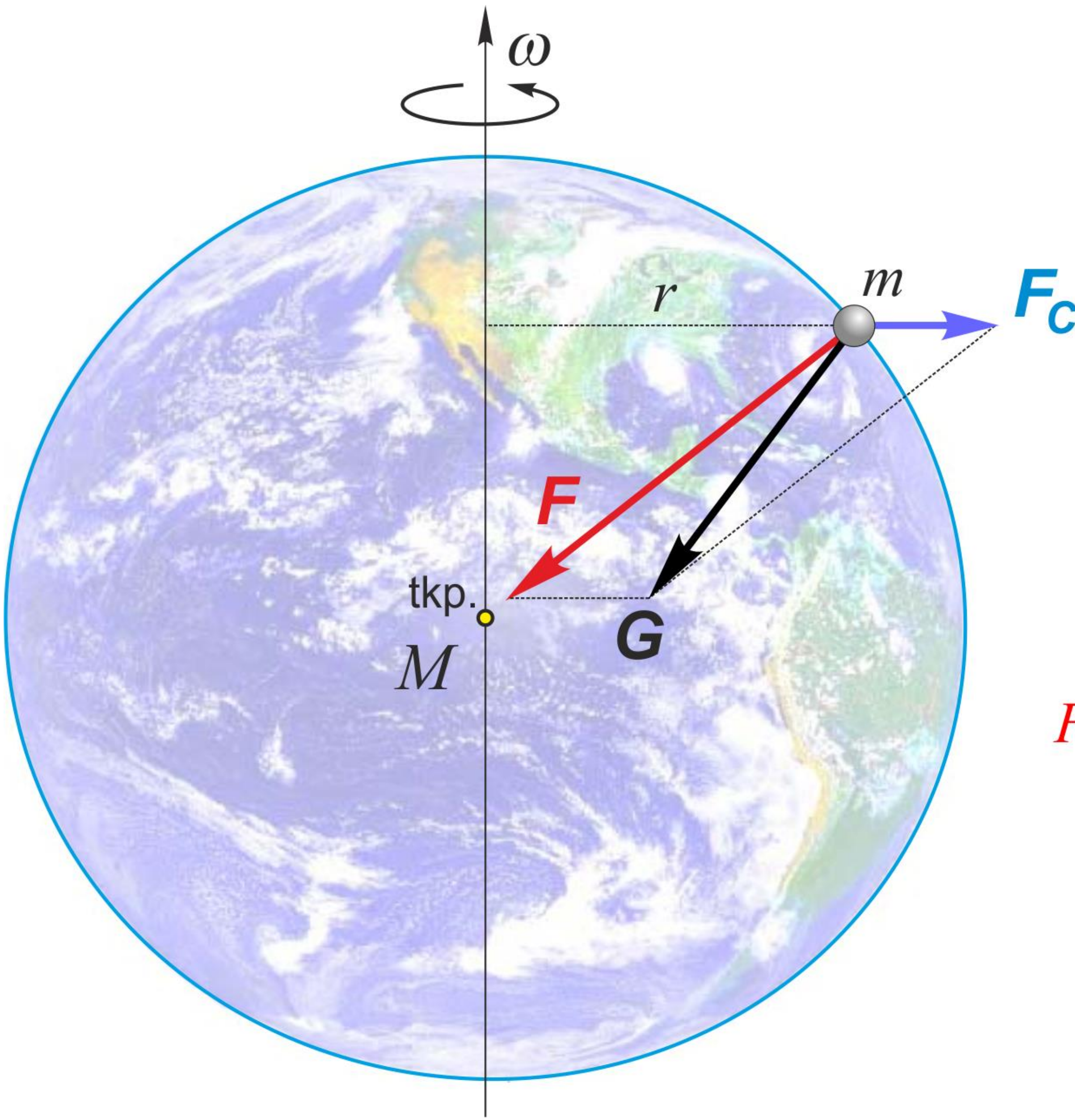


Galilo Galilei
1564-1642

Galilei (?)
Simon Stevin, 1586

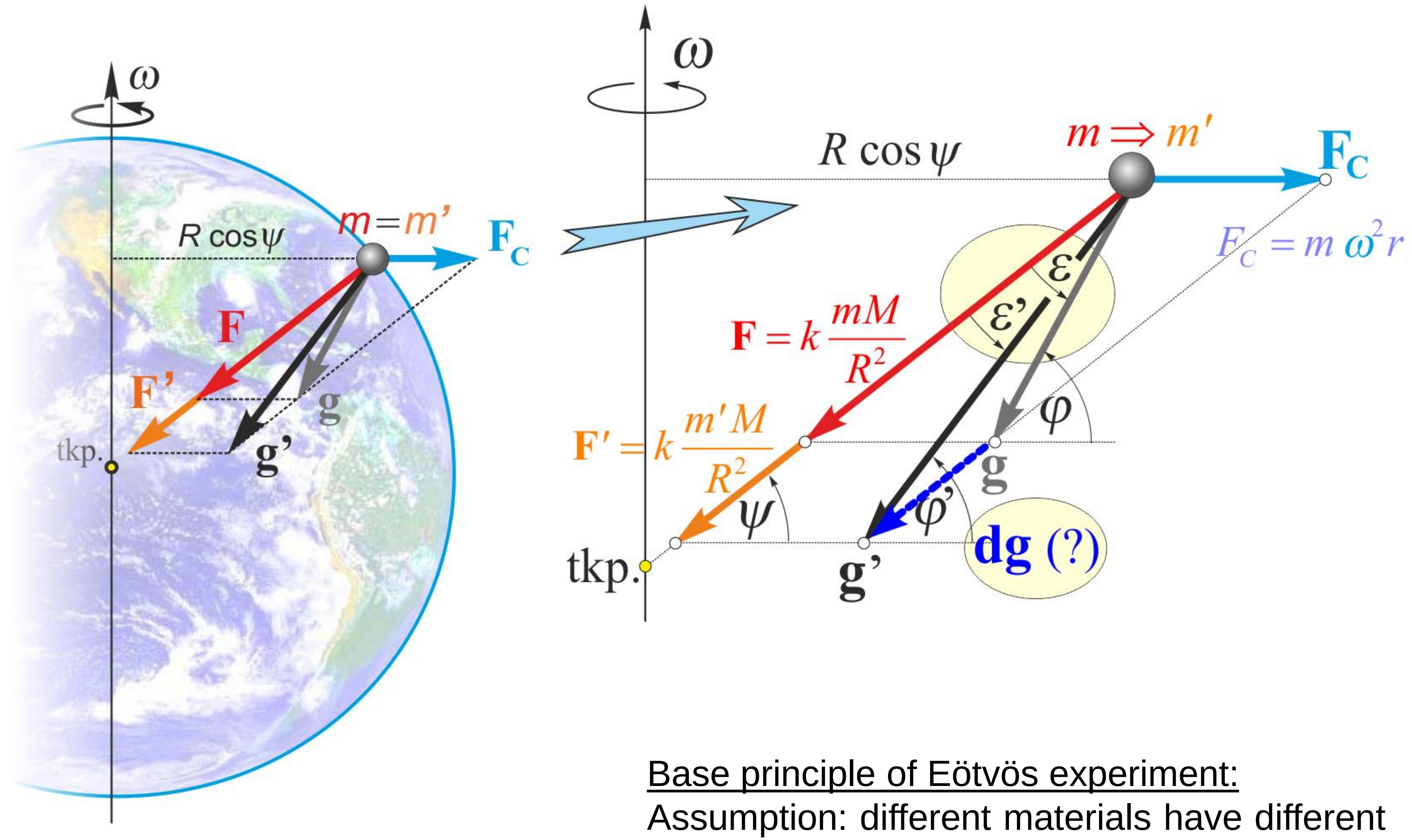
Base question:
Is the gravitation
depends on the material?





$$G = F + F_C \quad (+F_á)$$

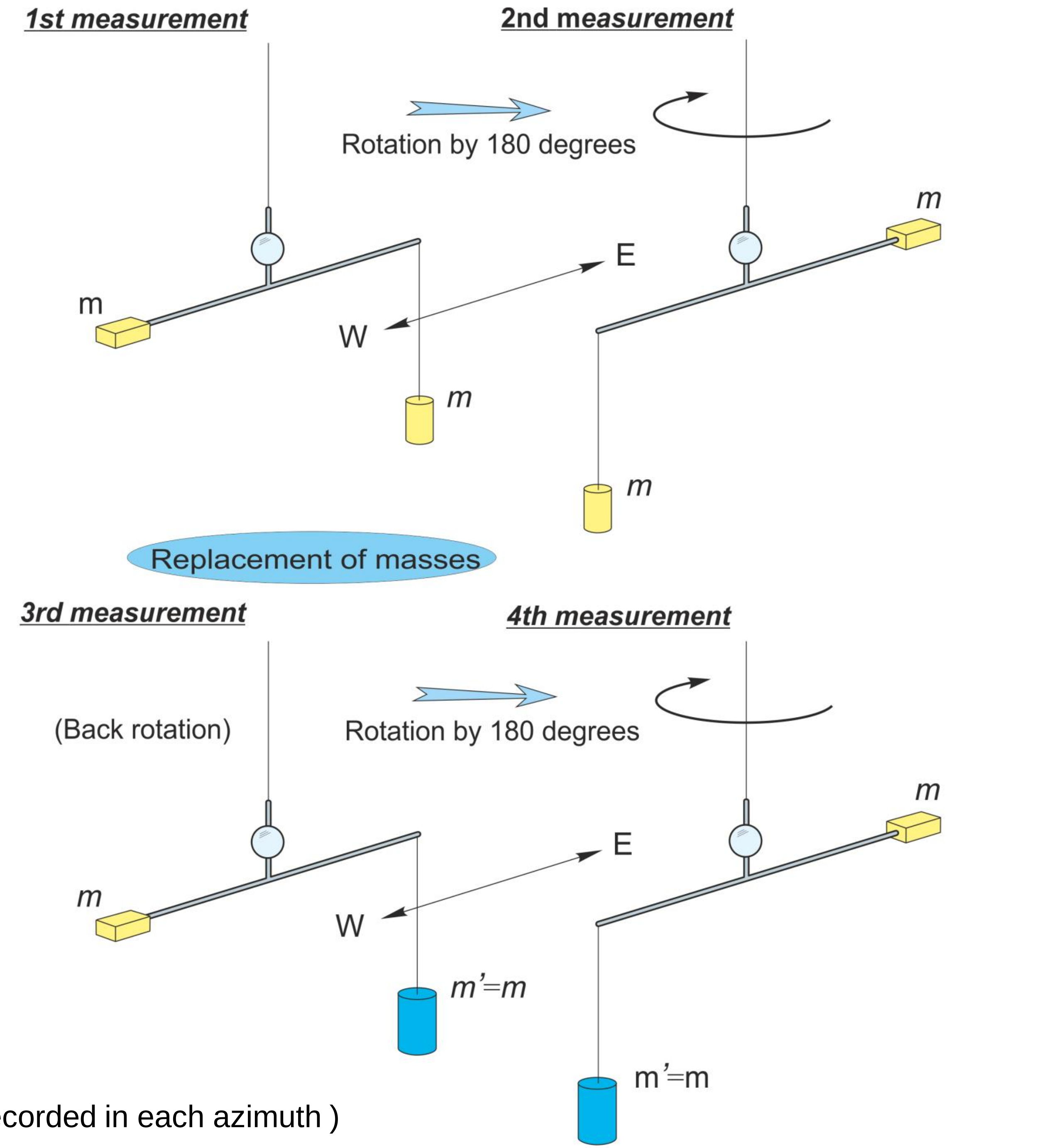
$$F = k\frac{mM}{R^2} \qquad F_C = m\,\omega^2 r$$



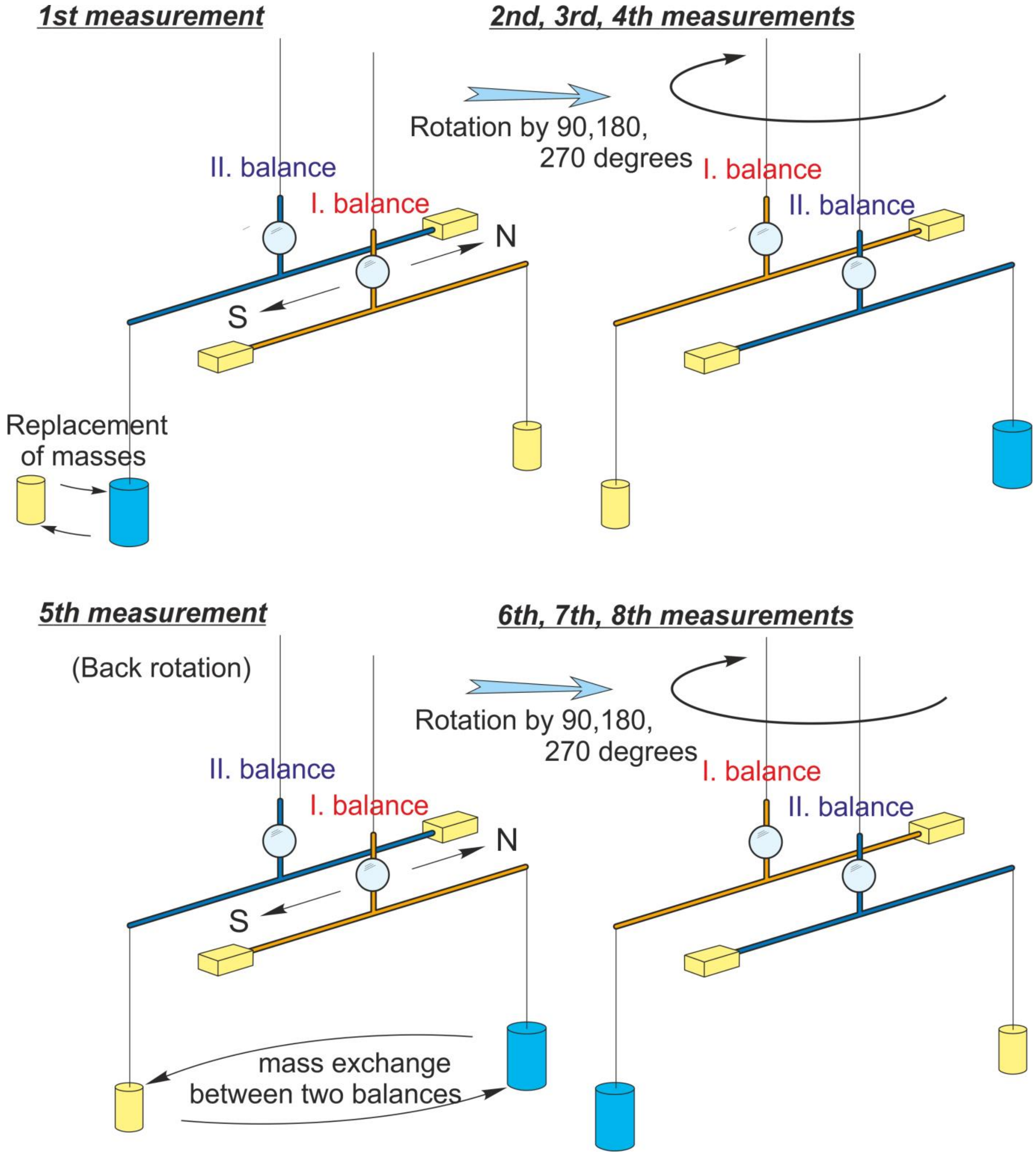
<u>Base principle of Eötvös experiment:</u>

Assumption: different materials have different gravitational forces but the same rotational centrifugal force.

Mass exchanging measurement strategy



(The damped position should be recorded in each azimuth)



1st measurement
2nd, 3rd, 4th measurements
Rotation by 90,180,
270 degrees
II. balance
I. balance
N
S
I. balance
II. balance
Replacement
of masses
5th measurement
6th, 7th, 8th measurements
(Back rotation)
Rotation by 90,180,
270 degrees
II. balance
I. balance
N
S
I. balance
II. balance
mass exchange
between two balances

The biggest enemy of the torsion balance measurements is the man himself!

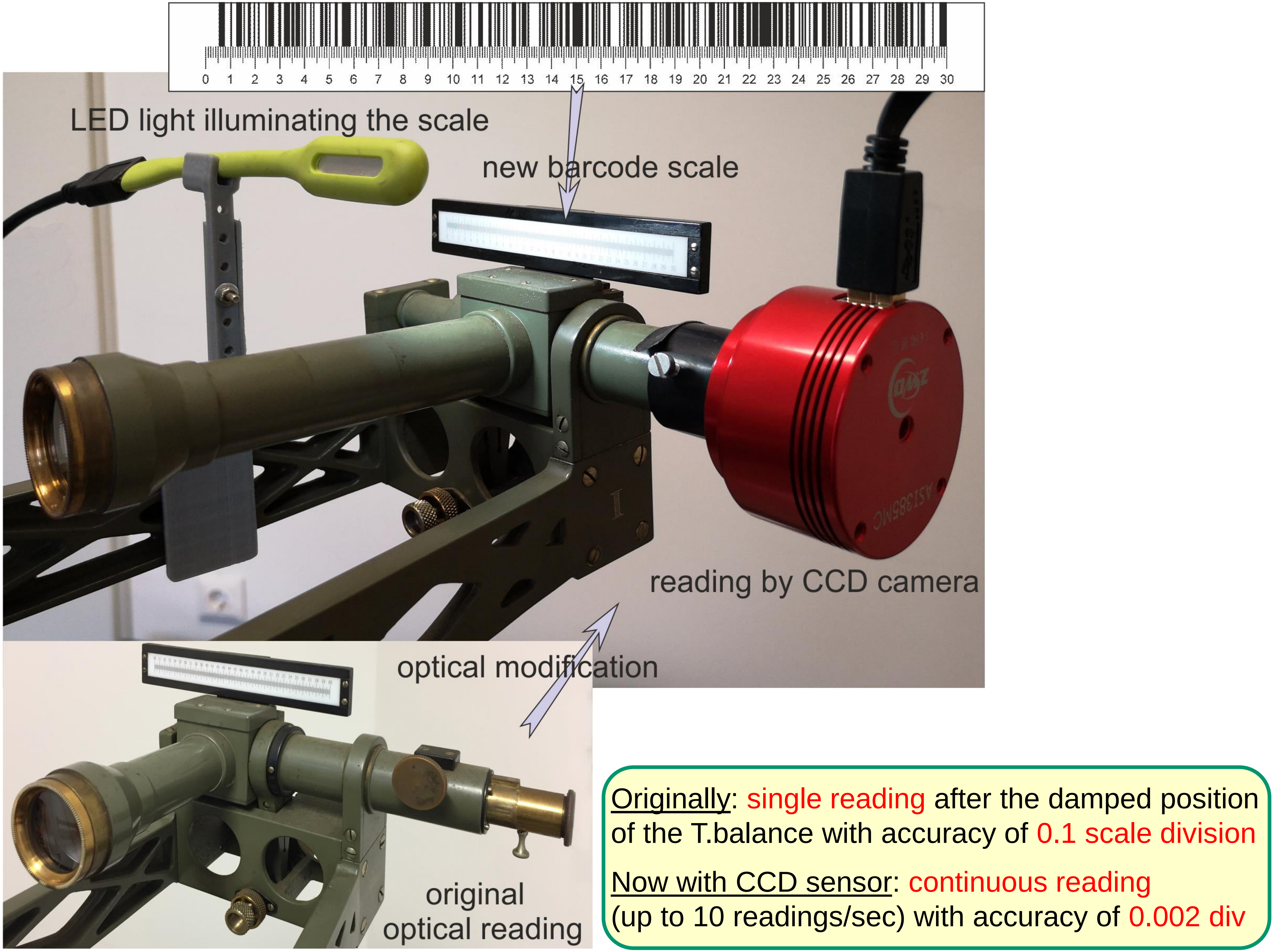
- ➢ The mass of the observer's body changes the damped position of the torsion balance,
- ➢ Going to instrument the noise of the observer's steps cause ground vibrations, which also disturbs the damped position of the torsion balance.

Solution for these problems ***two important enhancements:***

1. *Computer-controlled scan on a CCD sensor instead of visual reading*
2. *Using remote-controlled rotation mechanics*

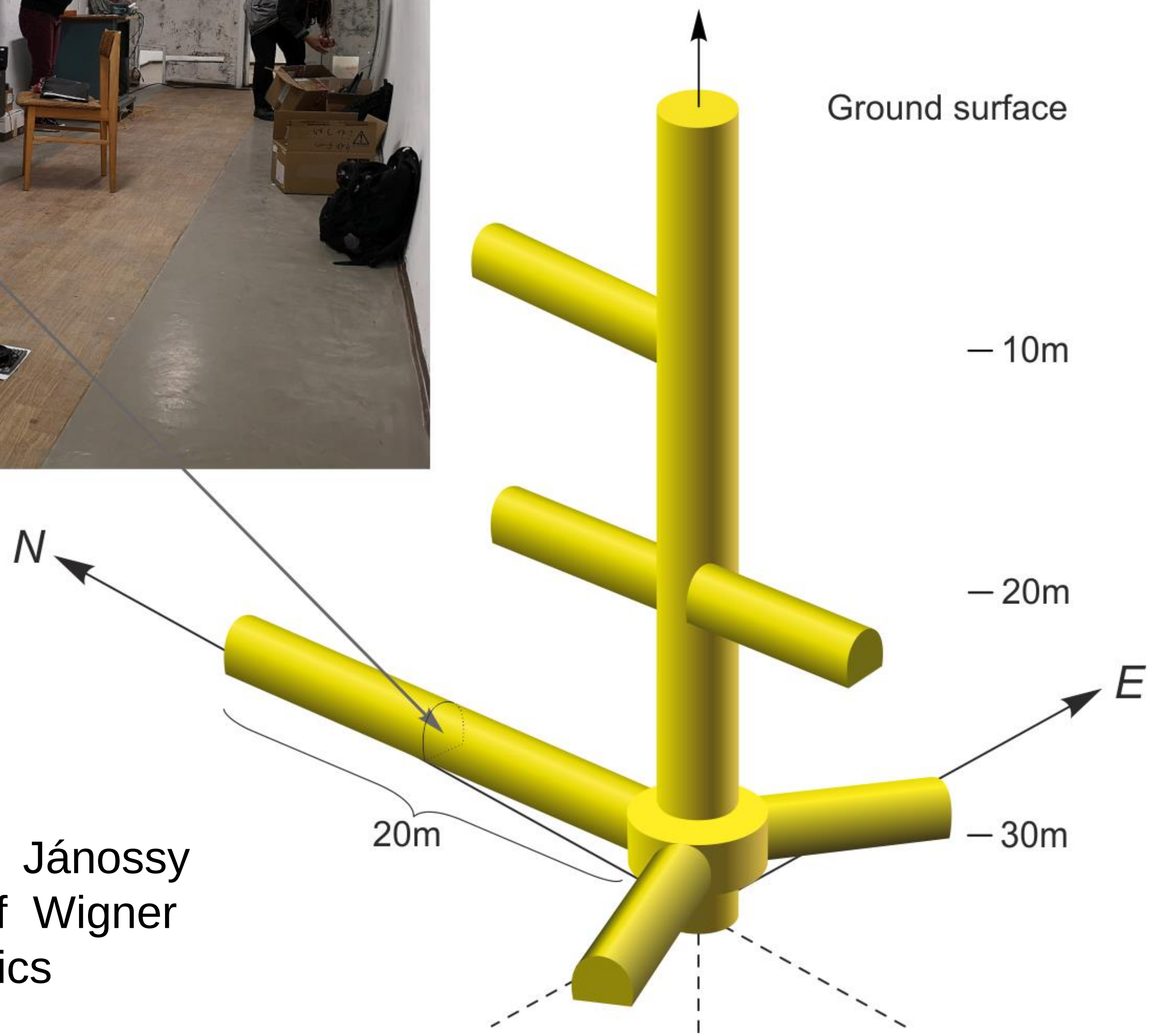
Preparing the Eötvös-Pekár torsion balance for Eötvös experiment

The preparatory work of the measurements took place for more than one year at the Department of Geodesy and Surveying of BME

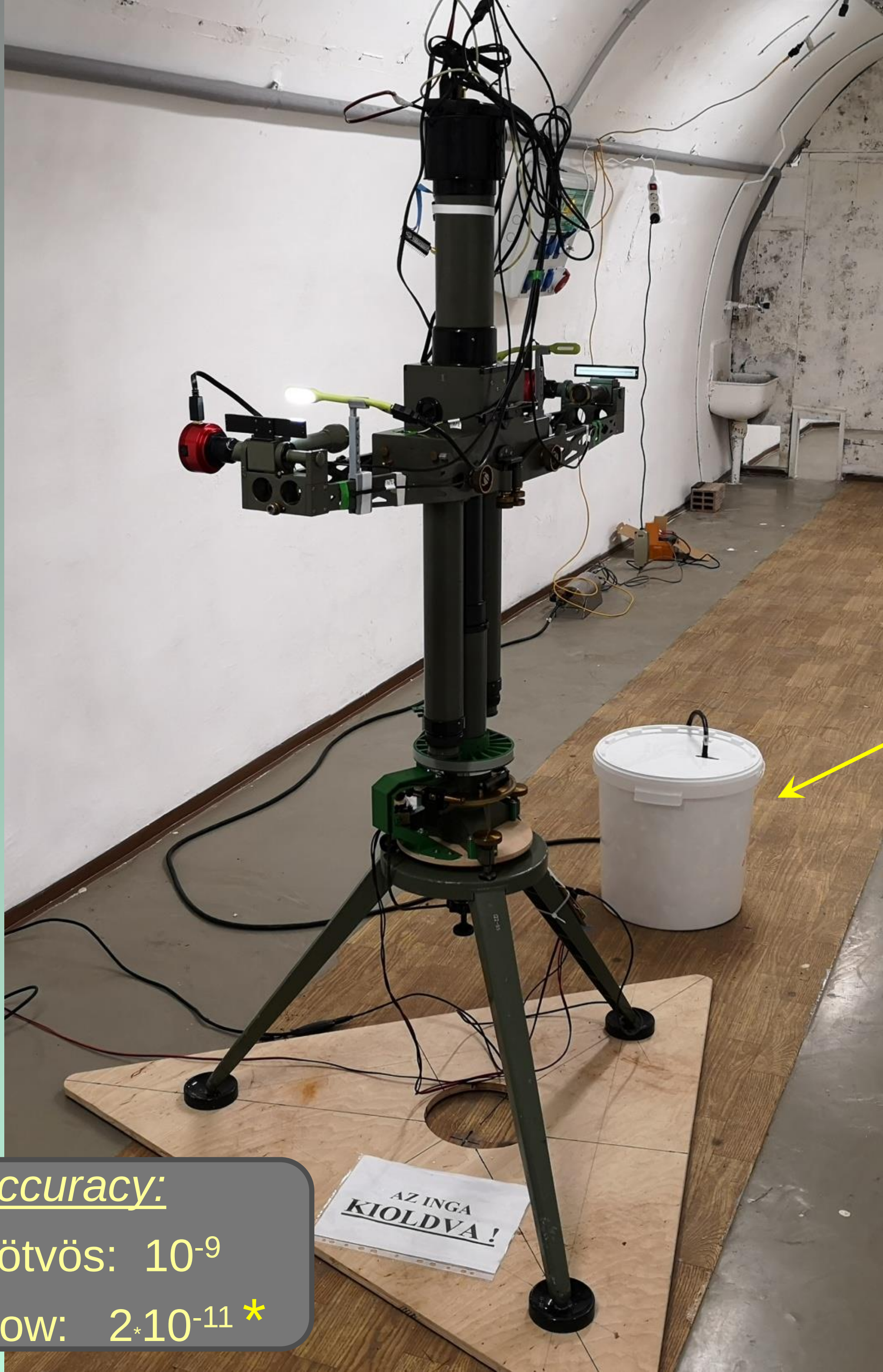

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
LED light illuminating the scale
new barcode scale
reading by CCD camera
optical modification
original
optical reading
Originally: single reading after the damped position of the T.balance with accuracy of 0.1 scale division
Now with CCD sensor: continuous reading (up to 10 readings/sec) with accuracy of 0.002 div

Computer-controlled rotation mechanics

Using RENISHAW optical encoder, position (azimuth) readout accuracy is under arcseconds



Location of measurements: Jánossy Underground Laboratory of Wigner Researche Center for Physics



Güralp 3T compact three-component broadband seismometer

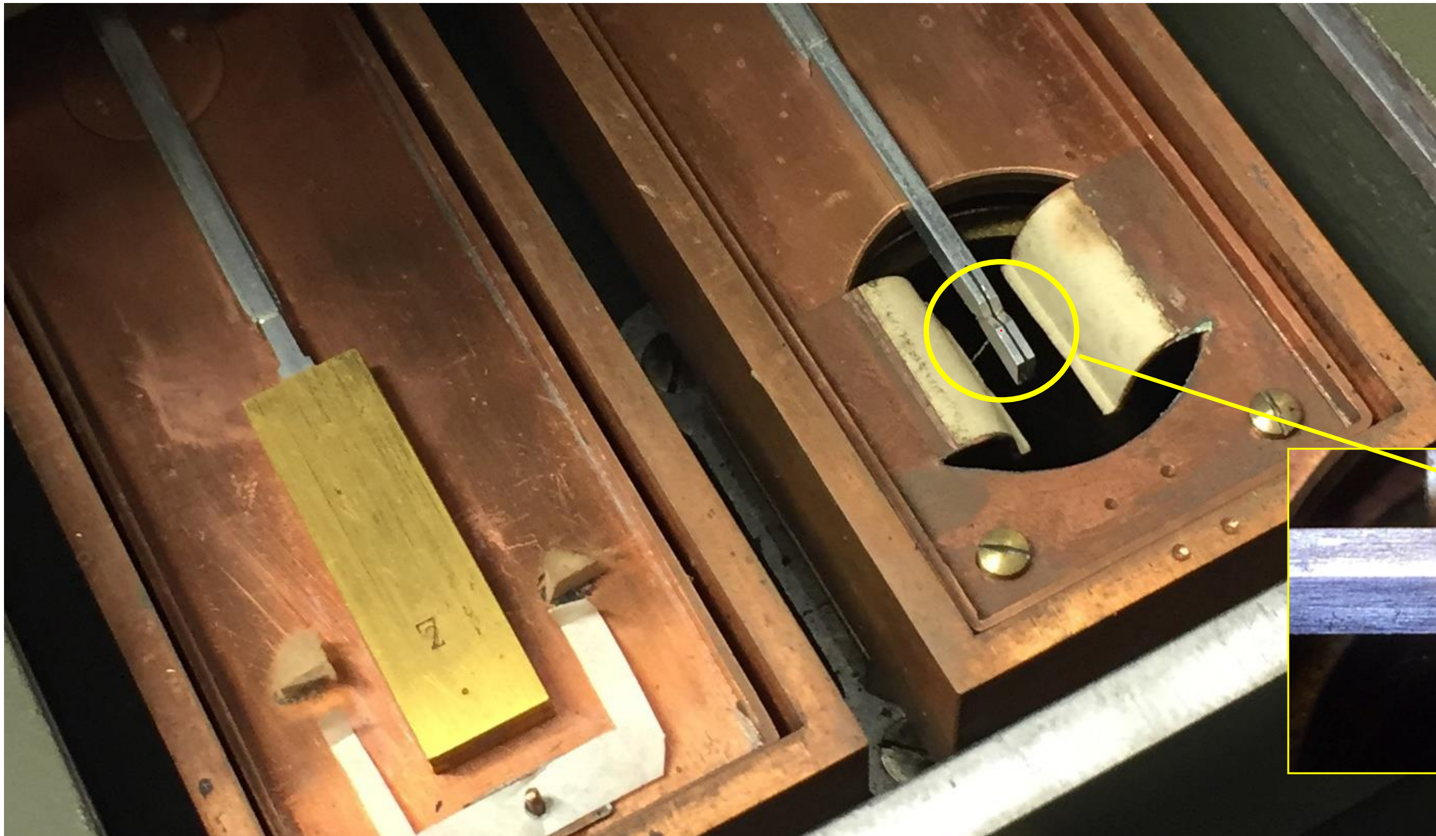
* Recently our biggest problem is the elimination of the small microseismic ground vibrations and the infrasound pressure changes

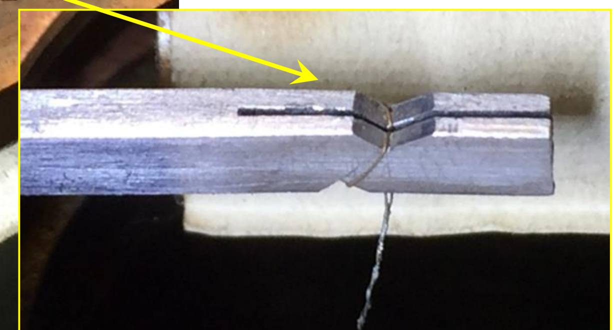
Accuracy:

Eötvös: 10^{-9}

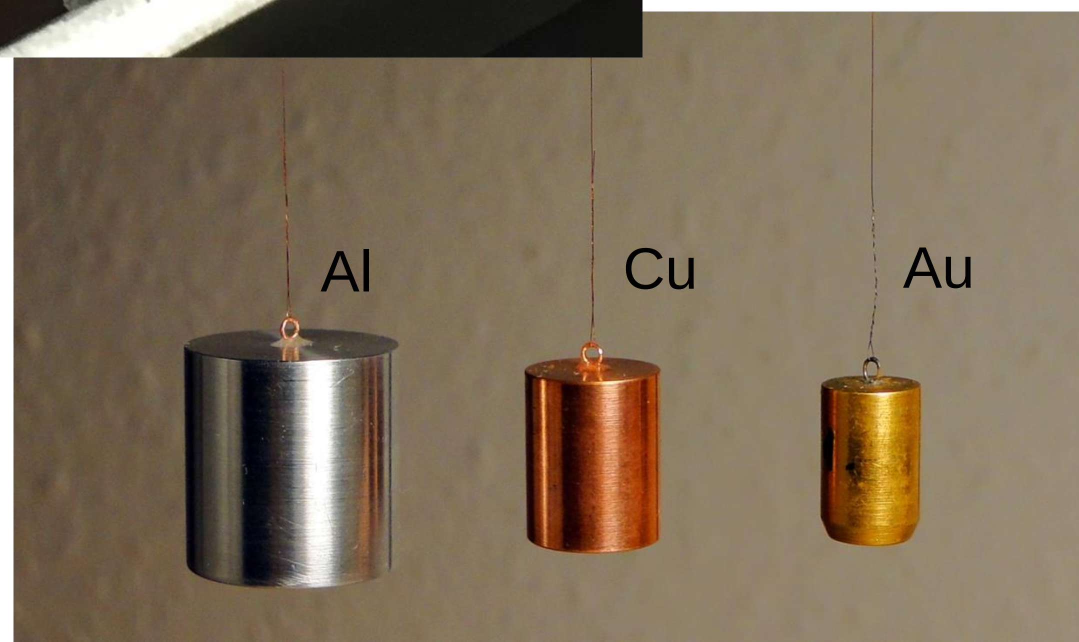
Now: $2 \cdot 10^{-11}$ *

Tömegcserék





Replacement of test masses



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United Nations
Educational, Scientific and
Cultural Organization
100th anniversary of Roland Eötvös
(1848-1919), physicist, geophysicist,
and innovator of higher education
Commemorated in association with UNESCO
An important event:
the actual equivqalence measurements started at night on May 14. 2019.
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100th anniversary of Roland Eötvös (1848-1919), physicist, geophysicist, and innovator of higher education
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United Nations Educational, Scientific and Cultural Organization

Present state:

- Preparation of the measurement site is completed.
- Torsion balance has been restructured.
- Calibration measurements have been made.
- The new remote controlled rotation mechanism works well.
- CCD sensors, Led light illuminating and the scales are suitable for the measurements.
- The necessary control and evaluation software have been written and tested.
- Some of the test masses have been made, the replacement of masses is solved.
- *Equivalence measurements started*.

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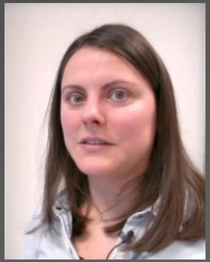
The staff of the experiment:


Völgyesi L.


Szondy Gy.


Tóth Gy.


Ván P.


Fenyvesi E.


Kiss B.


Péter G.


Harangozó P.


Gróf Gy.


Lévai P.


Barnaföldi G.


Deák L.


Égető Cs.


Somlai L.

In the next presentation Tóth Gy. takes a report about the measurements and the first results