9

Water bombs

Mário Lipovský

Task

Some students are ineffective in water balloon fights as the balloons they throw rebound without bursting.

Investigate the motion, deformation, and rebound of a balloon filled with fluid.

Under what circumstances does the balloon burst?

Content

- Motion and deformation
  - Two types
- Rebound
  - Angle of rebound
- Burst
  - Energies in balloon
    - Elastic
    - Kinetic
    - Potential
- Summary

How it looks

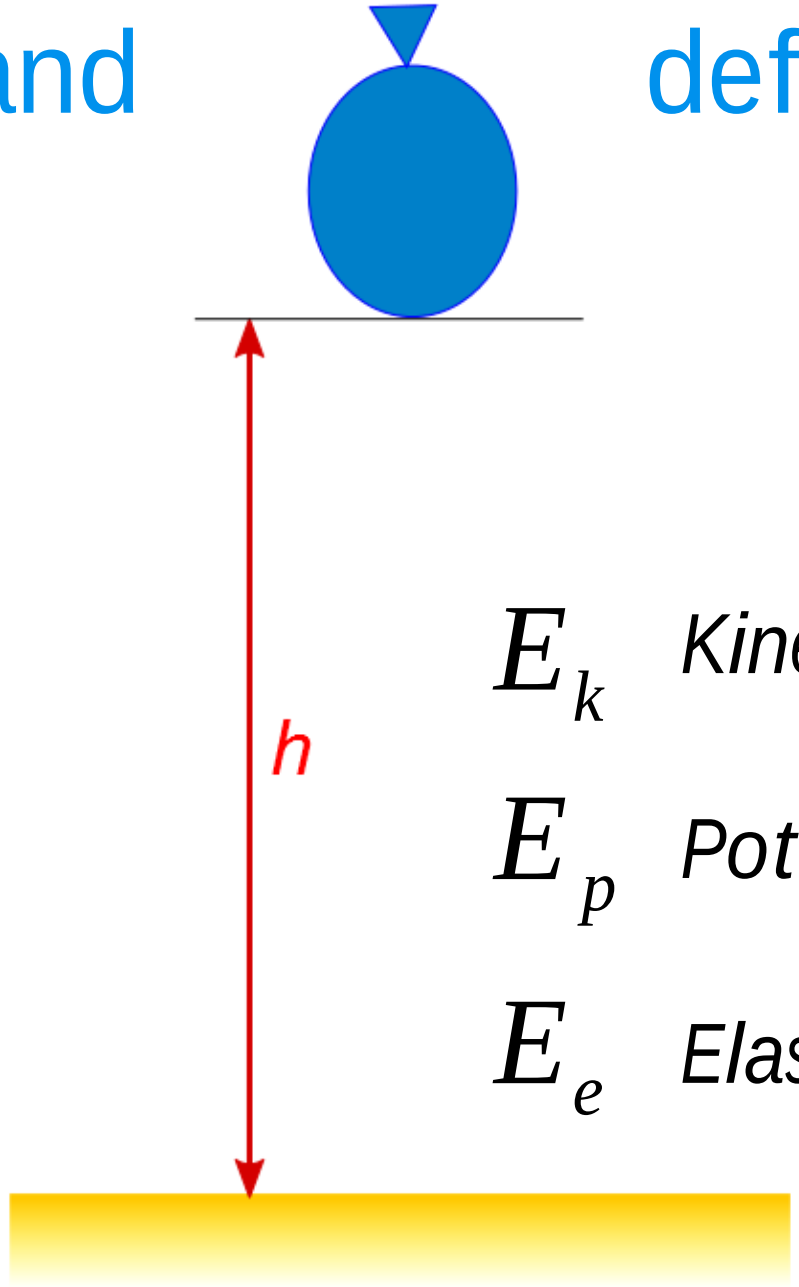
How it looks

Motion and deformation

$$E_k = 0$$

$$E_p = mgh$$

$$E_e = A$$



E_k *Kinetic energy*

E_p *Potential energy*

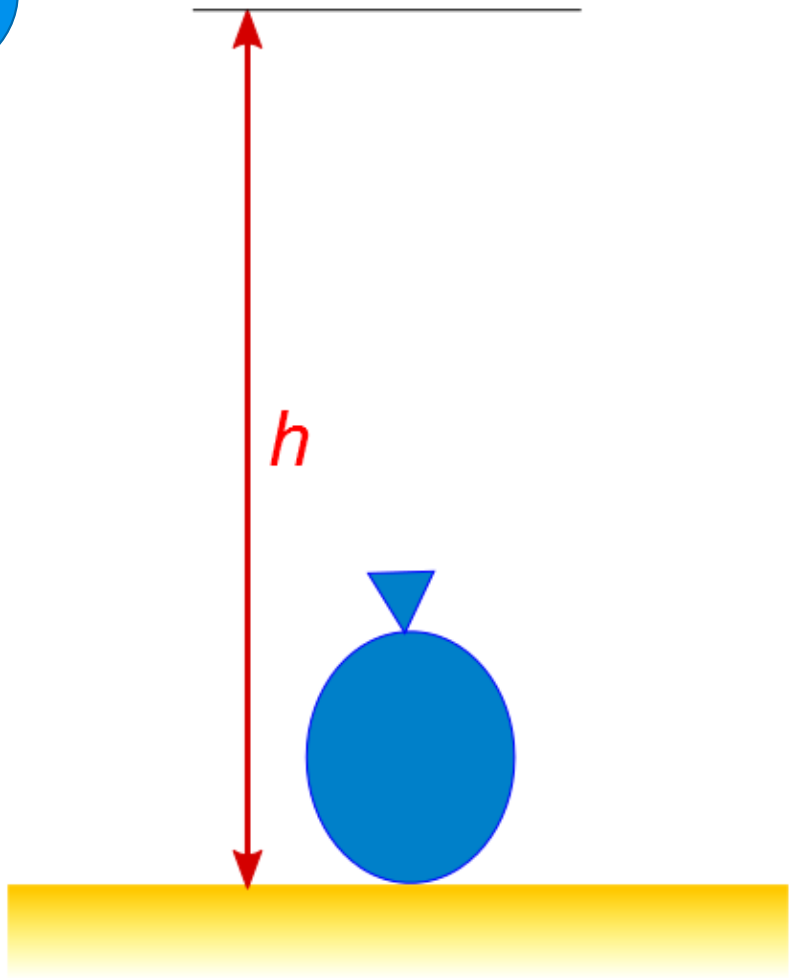
E_e *Elastic energy*

Motion and deformation

$$E_k = mgh$$

$$E_p = 0$$

$$E_e = A$$



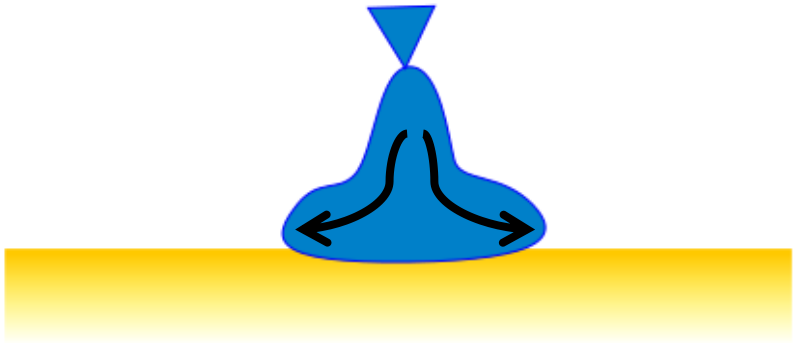
Motion and deformation

$$E_k = mgh - \Delta E$$

$$E_p = 0$$

$$E_e \approx A + \Delta E$$

Water flows to the sides



Motion and deformation

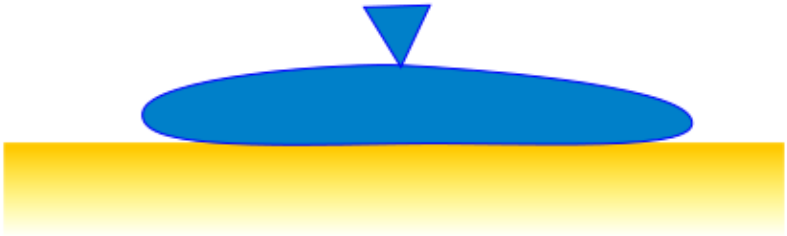
$$E_k = 0$$

$$E_p = 0$$

$$E_e \approx A + mgh$$

Maximal radius of balloon
Water stopped by rubber

Some energy lost
- water flows



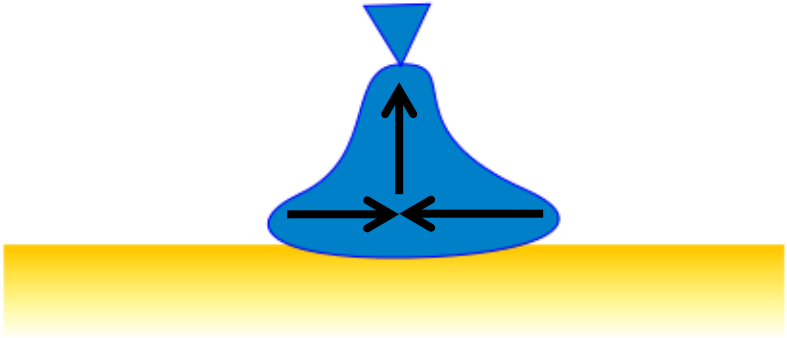
Motion and deformation

$$E_k = \Delta E$$

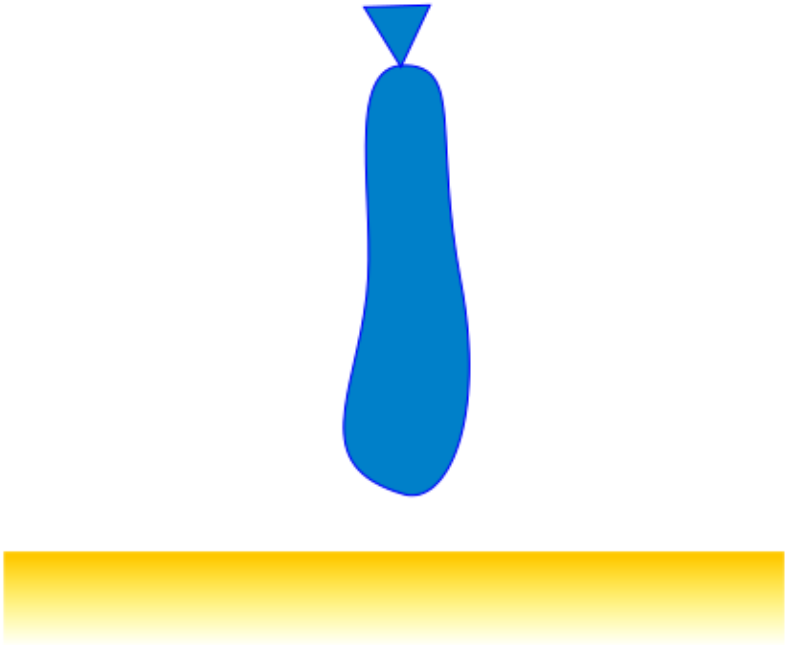
$$E_p = 0$$

$$E_e \approx A + mgh - \Delta E$$

Rubber is contracting



Motion and deformation



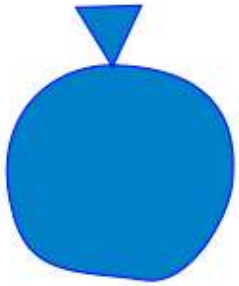
Motion and deformation

Motion and deformation

$$E_k = 0$$

$$E_p < mgh$$

$$E_e = A$$



Energy losses

Water convection

Heat

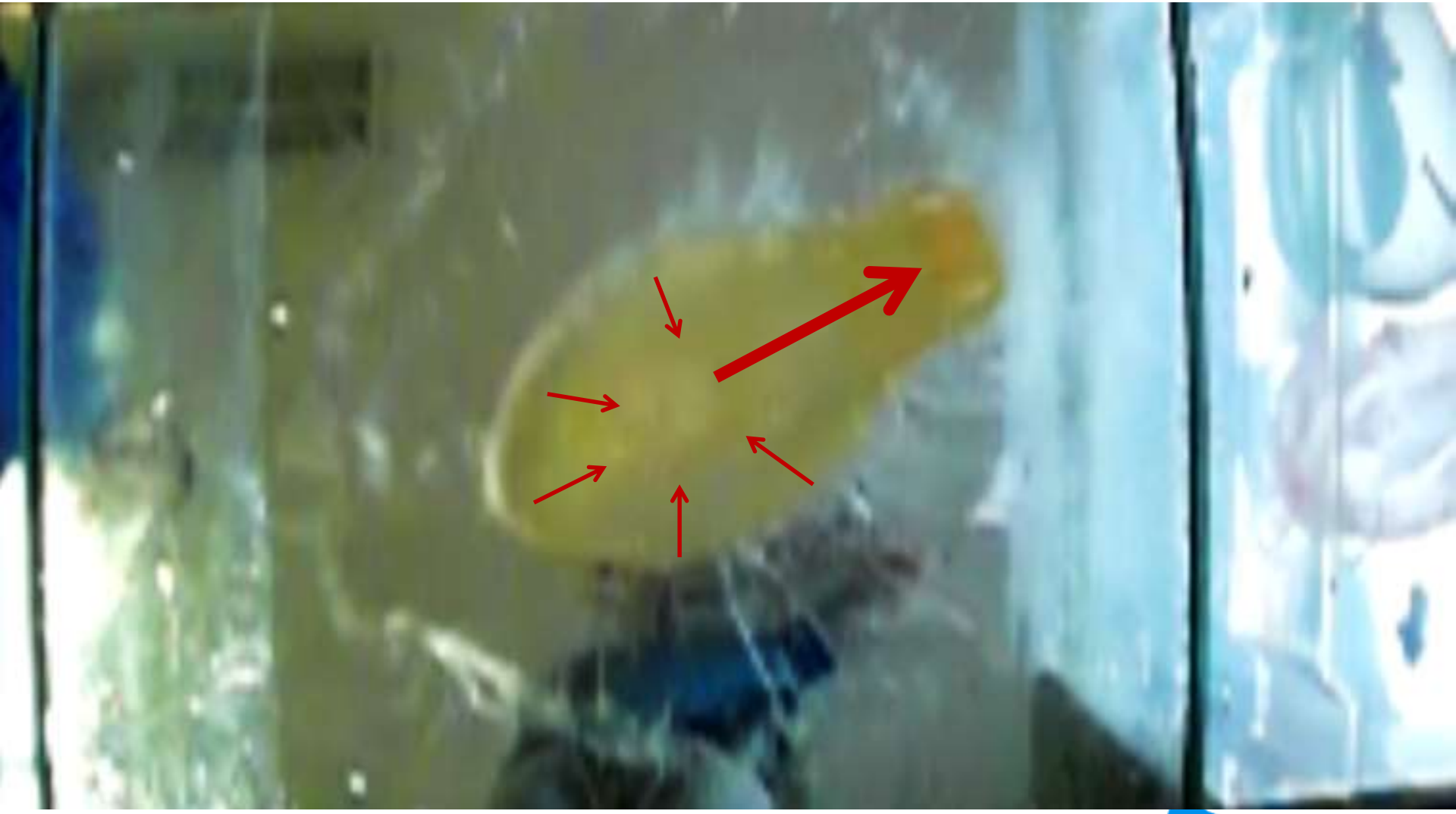
Different type of deformation

The view is from the bottom of the aquarium

Different type of deformation

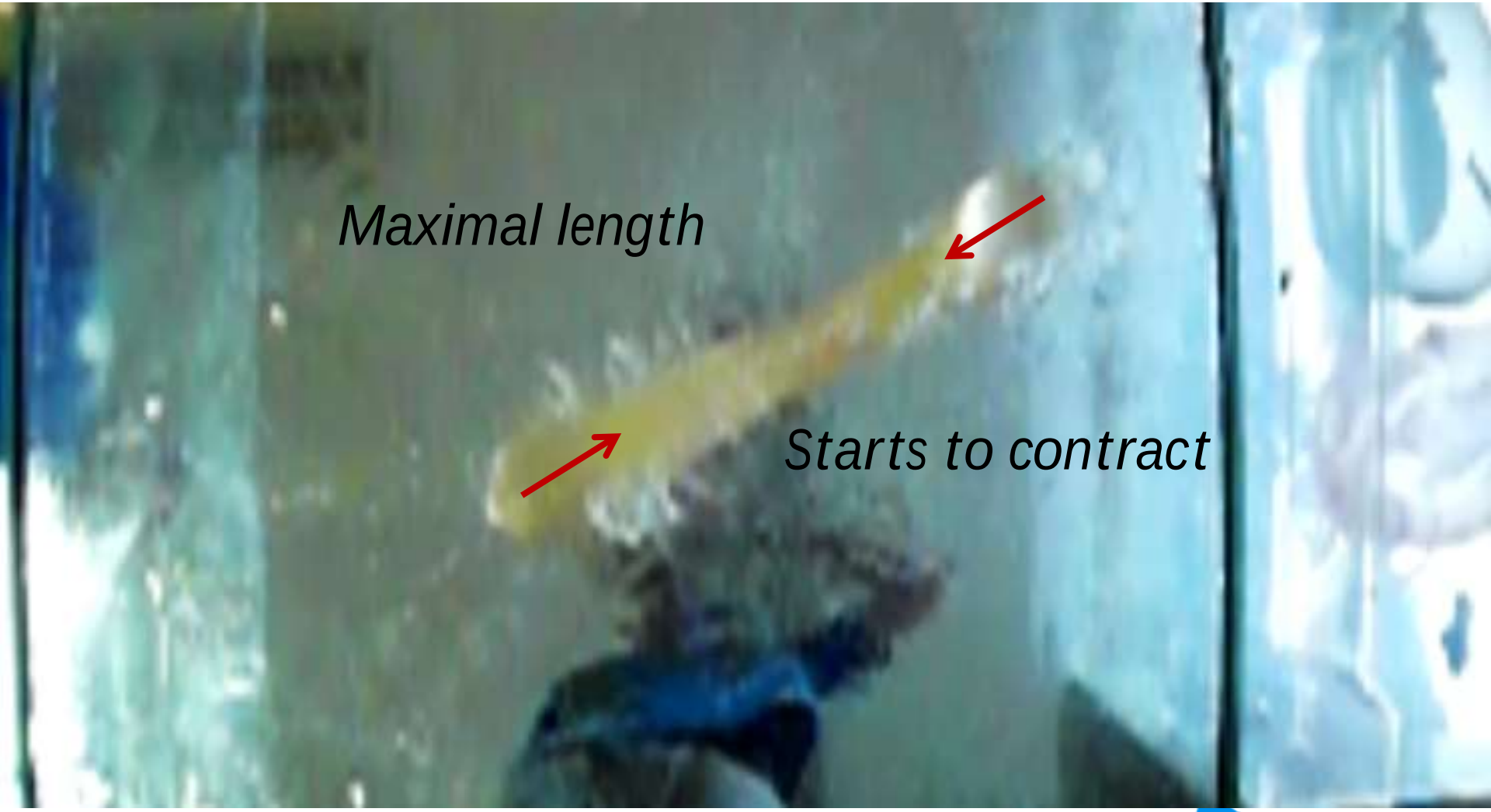
Different type of deformation

Different type of deformation



Different type of deformation

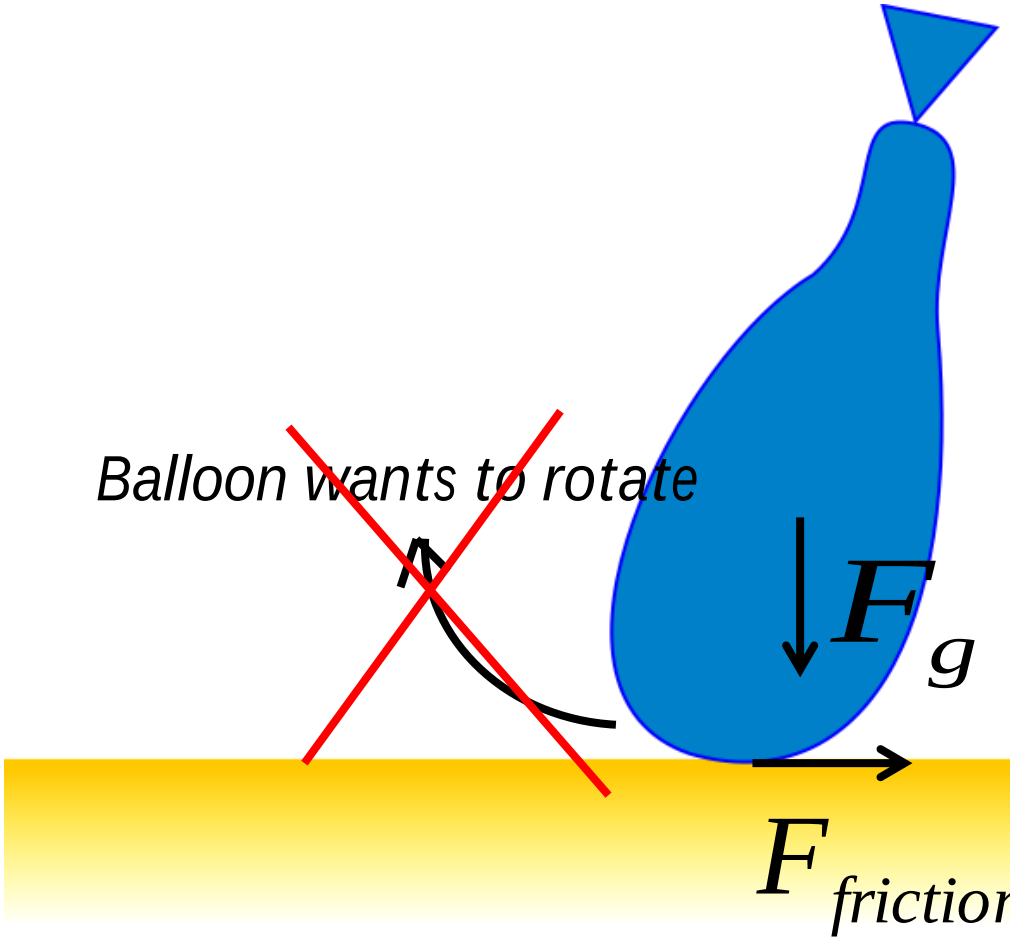
Different type of deformation



Different type of deformation

"*Investigate the motion, deformation and **rebound**...*"

Rebound



Balloon is accelerating in horizontal way

Jumps to the side

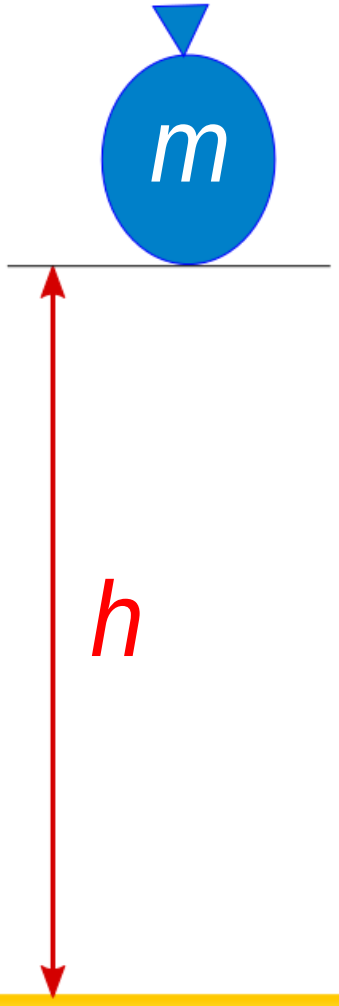
Jumping balloon

Jumping balloon

Jumping balloon

*"Investigate the motion, deformation, and rebound of a balloon filled with fluid. Under what circumstances does the balloon **burst?**"*

Apparatus



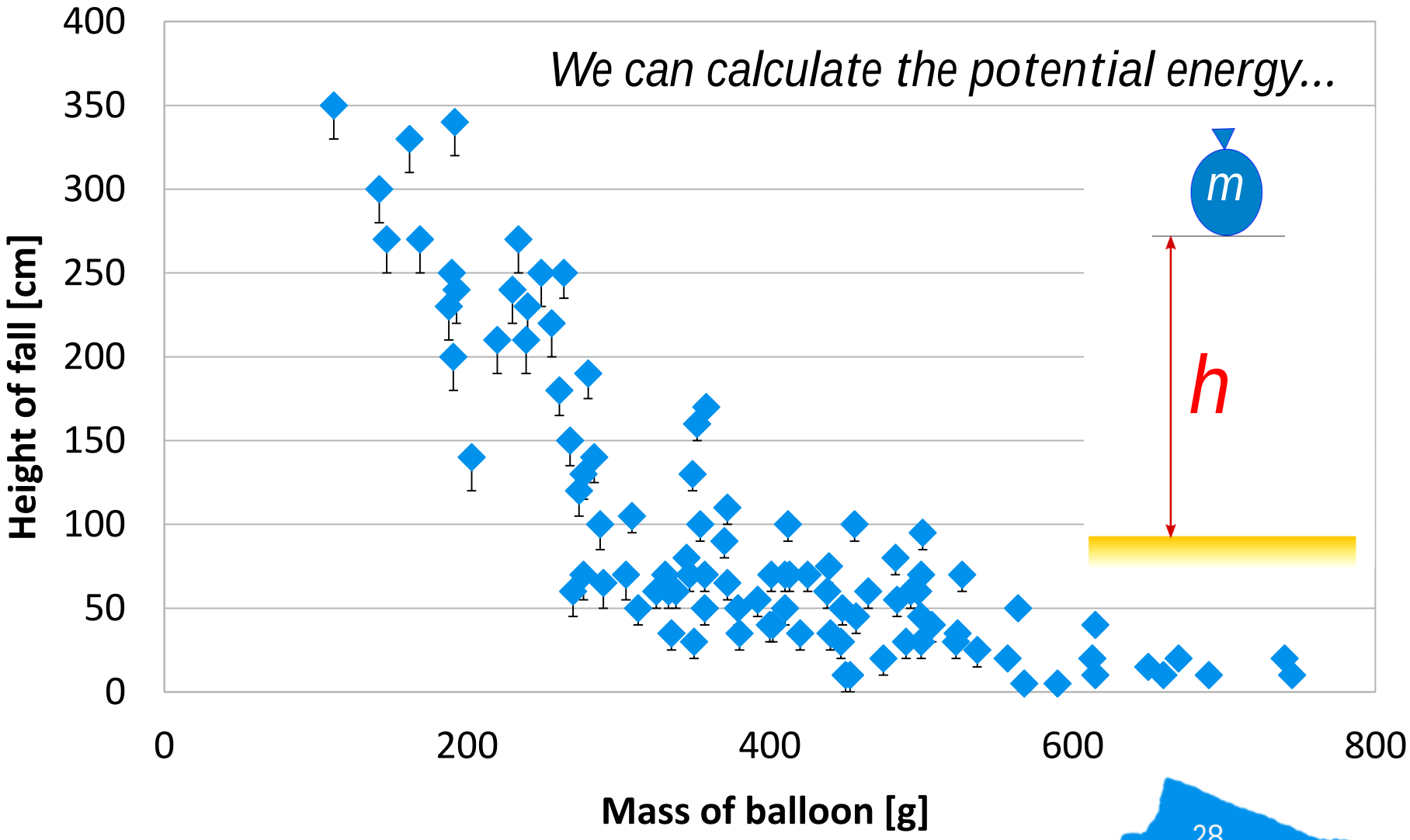
Balloon with mass m

Changing height h from h=0cm

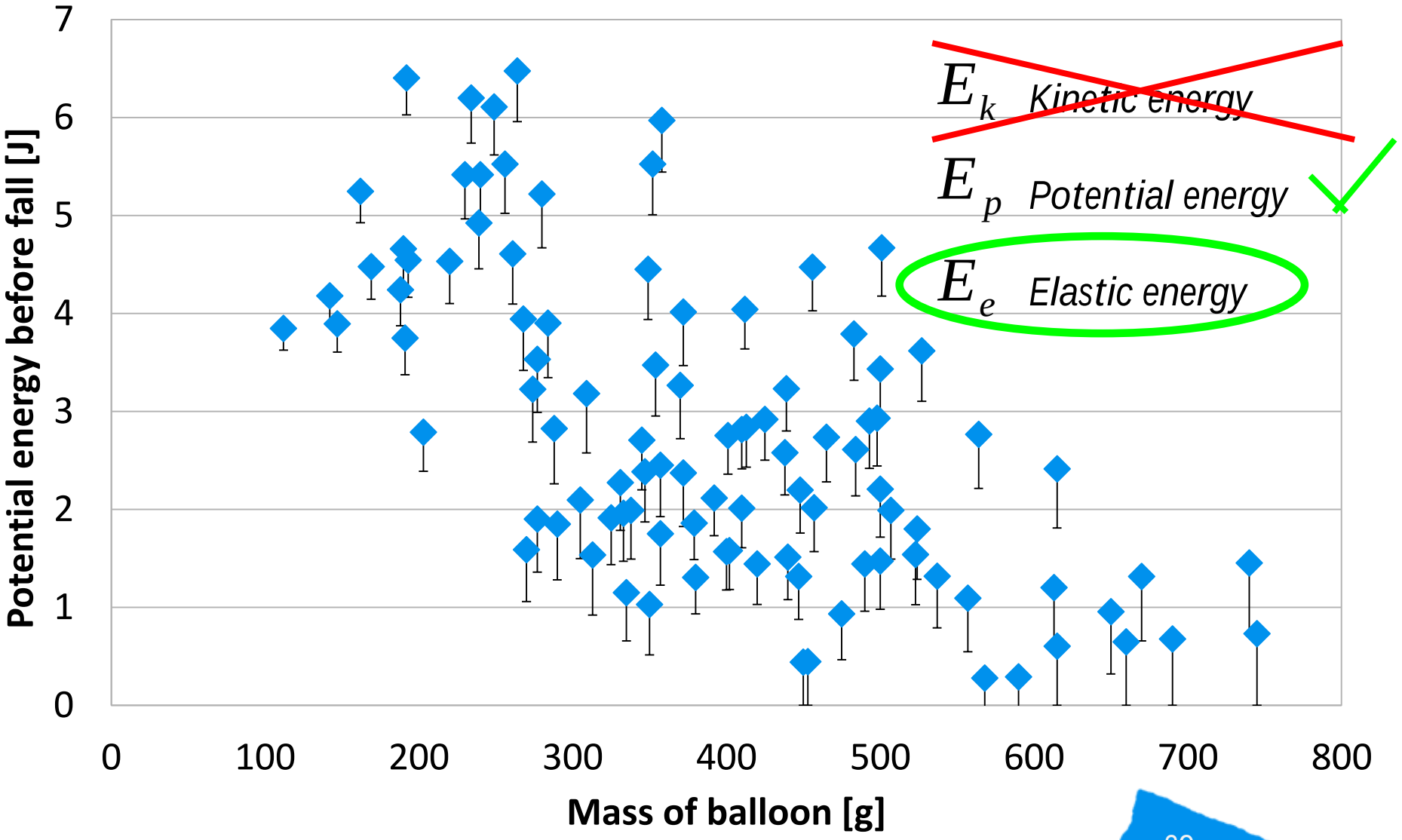
Find the smallest h, when it bursts

Do it with ***many*** balloons

Height, which causes burst

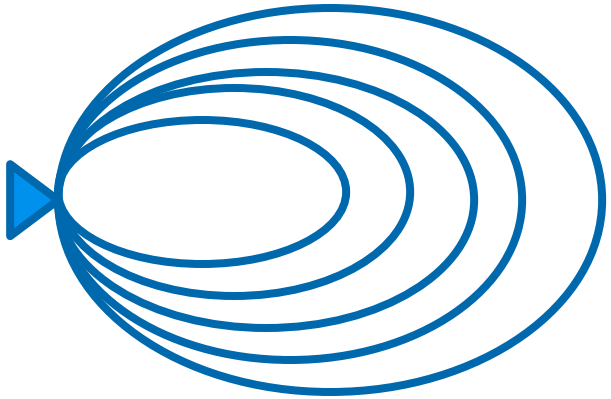


Potential energy needed to burst



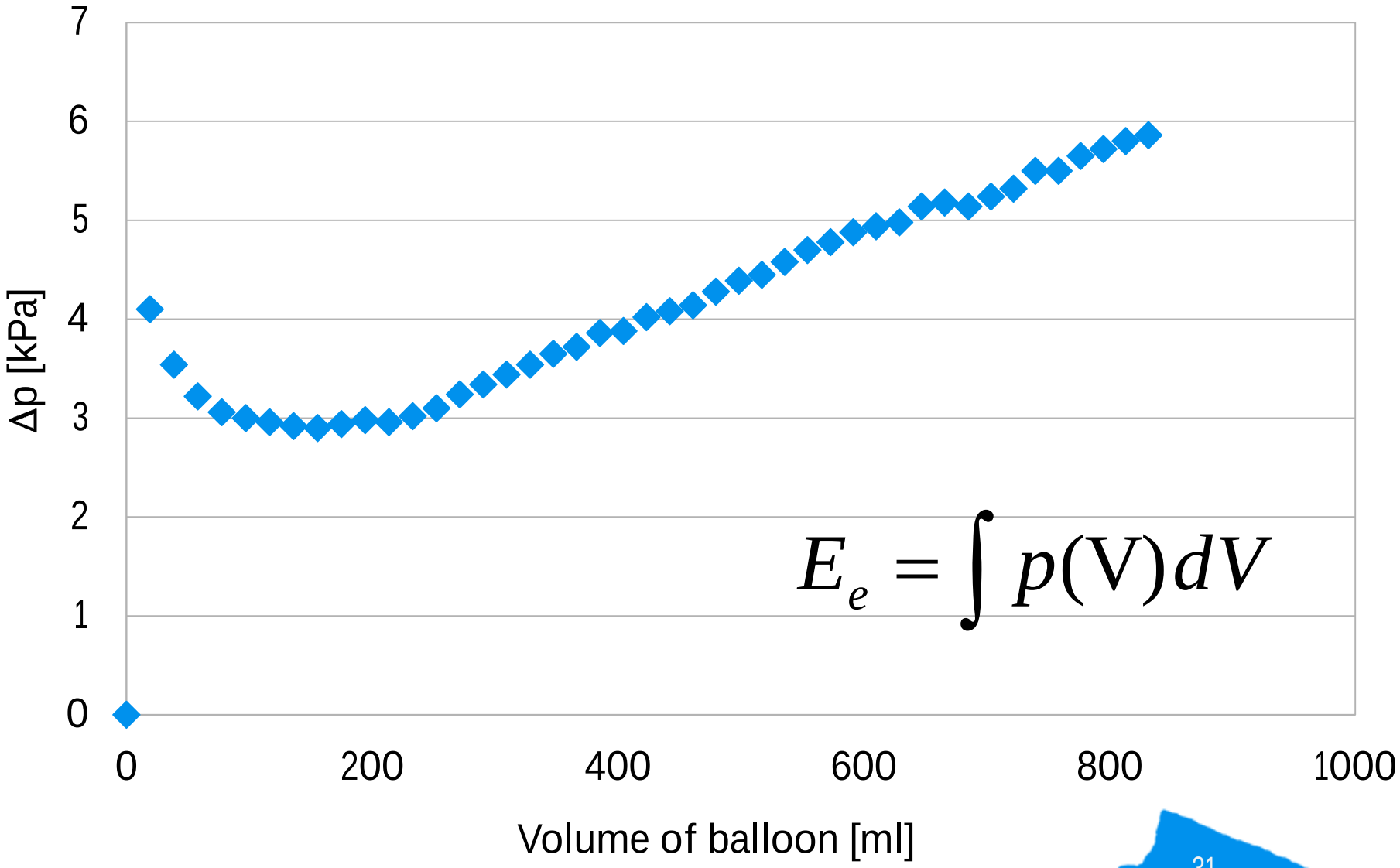
Elastic energy of balloon

Can be calculated from
pressure change during inflation

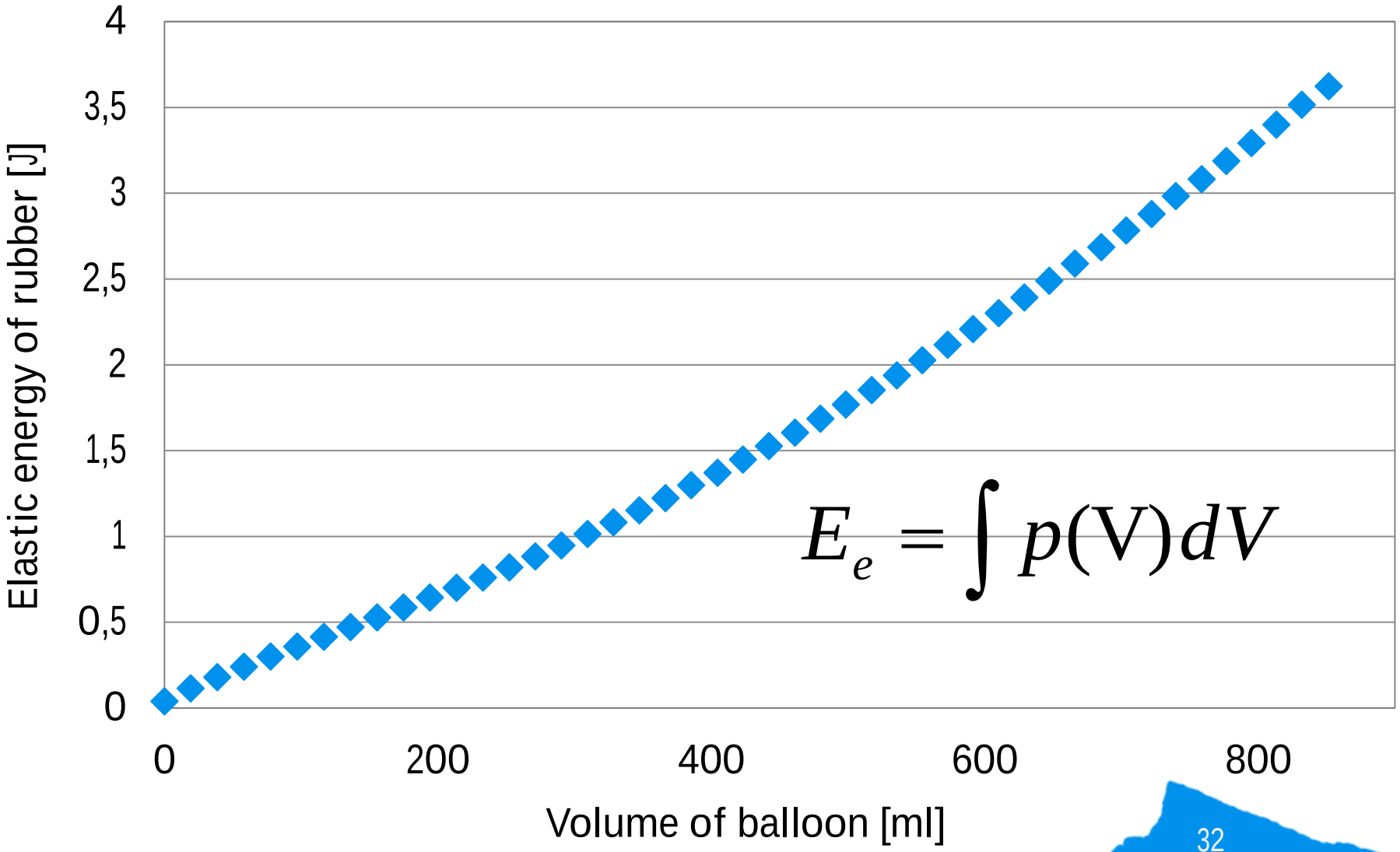


$$E_e = \int p(\mathrm{V})\,dV$$

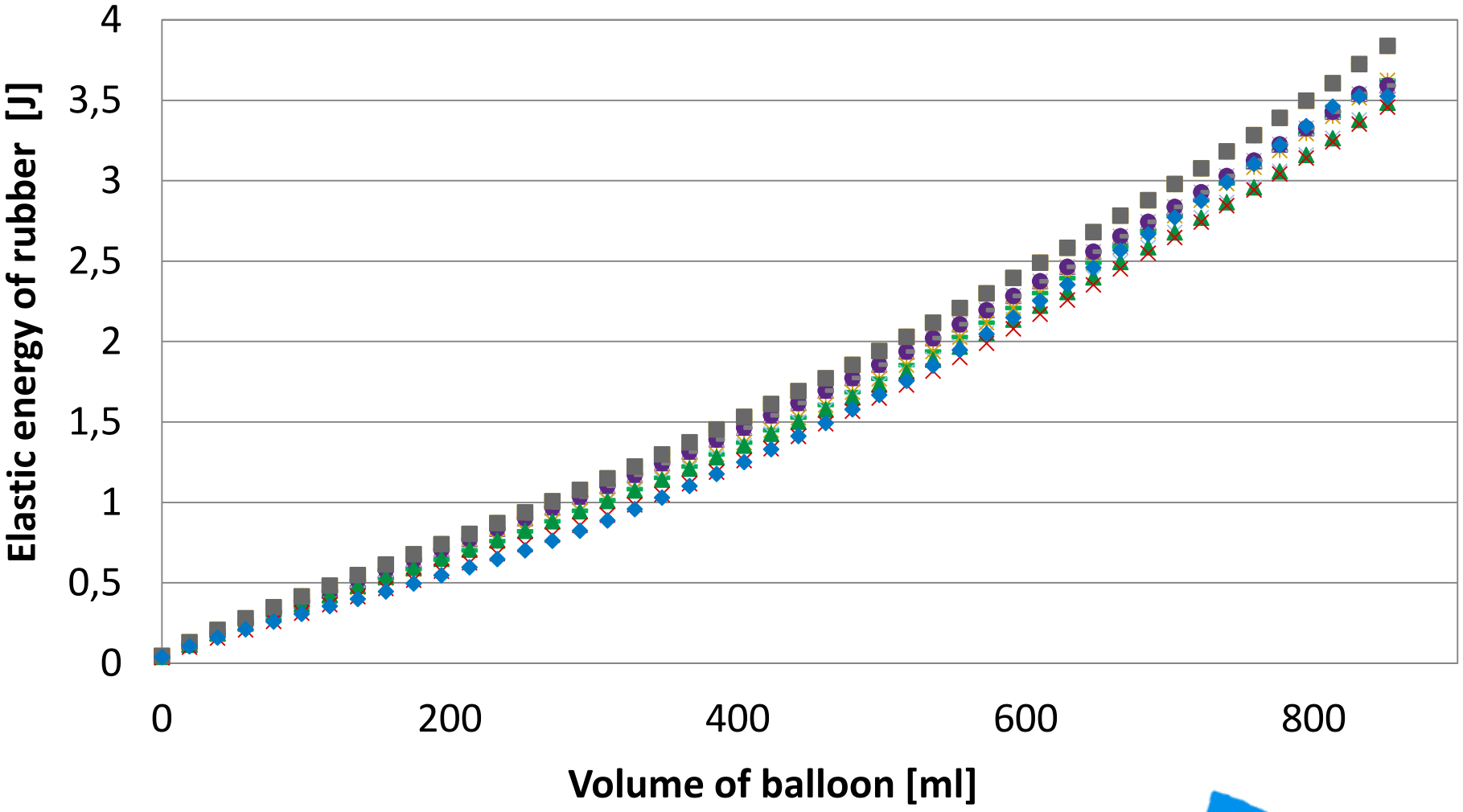
Pressure measurement



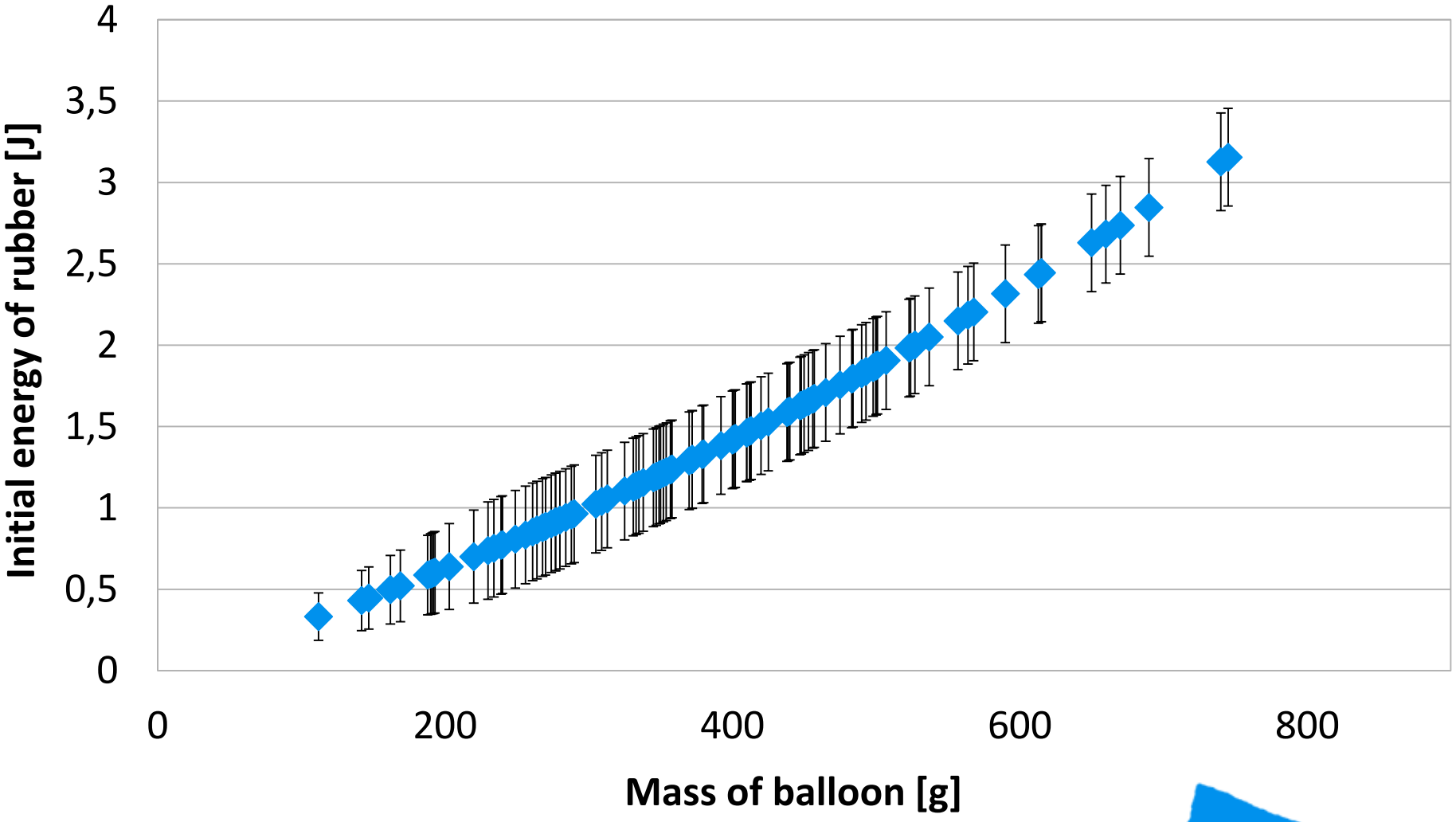
Elastic energy of balloon



More measurements of elastic energy

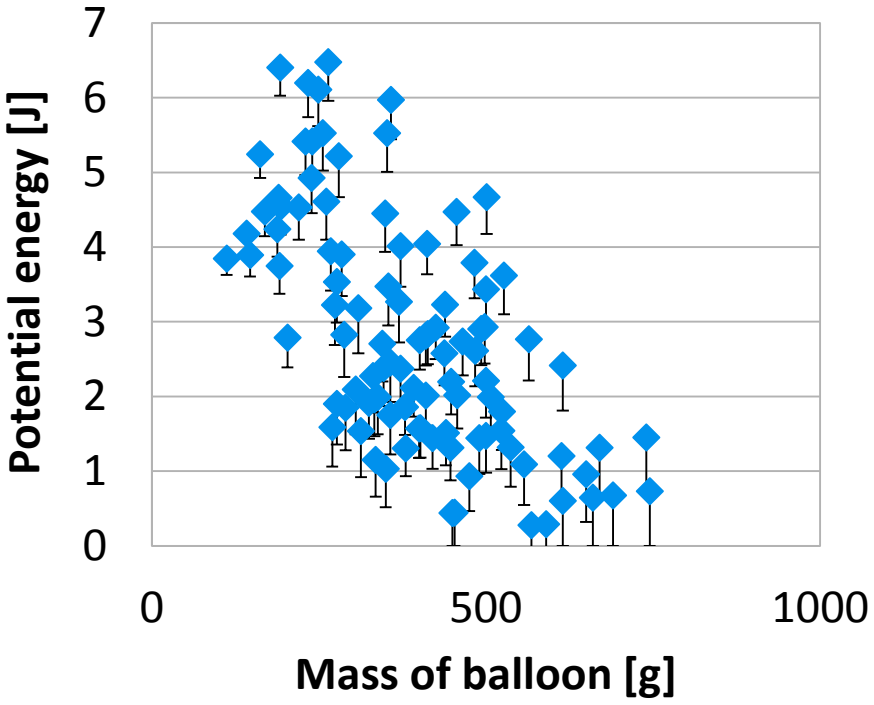


Elastic energy of balloon with water

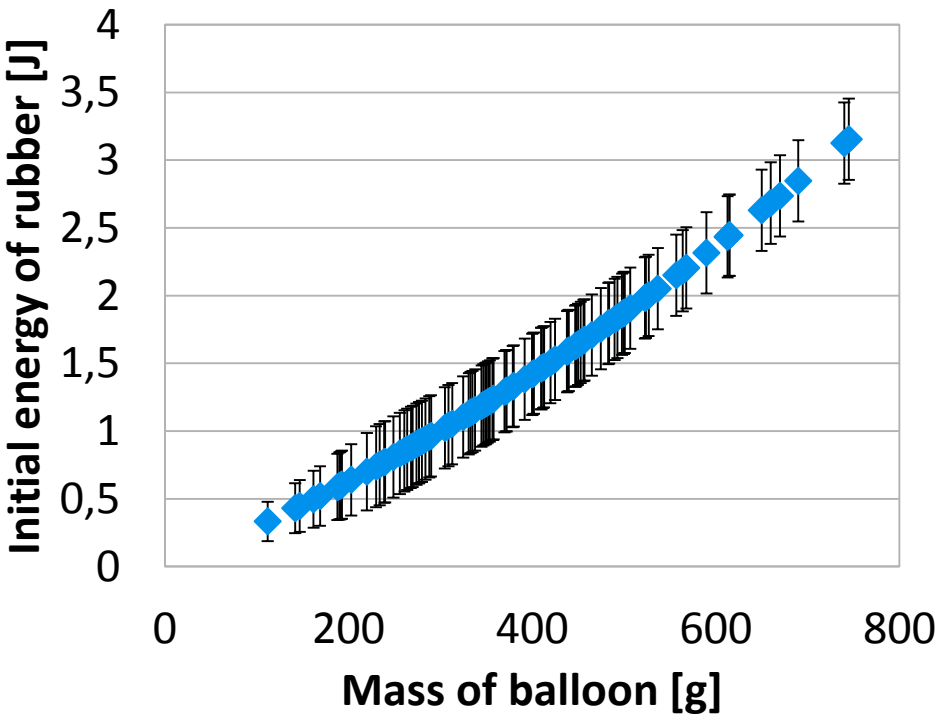


Total energy given to balloon

Potential energy of fall



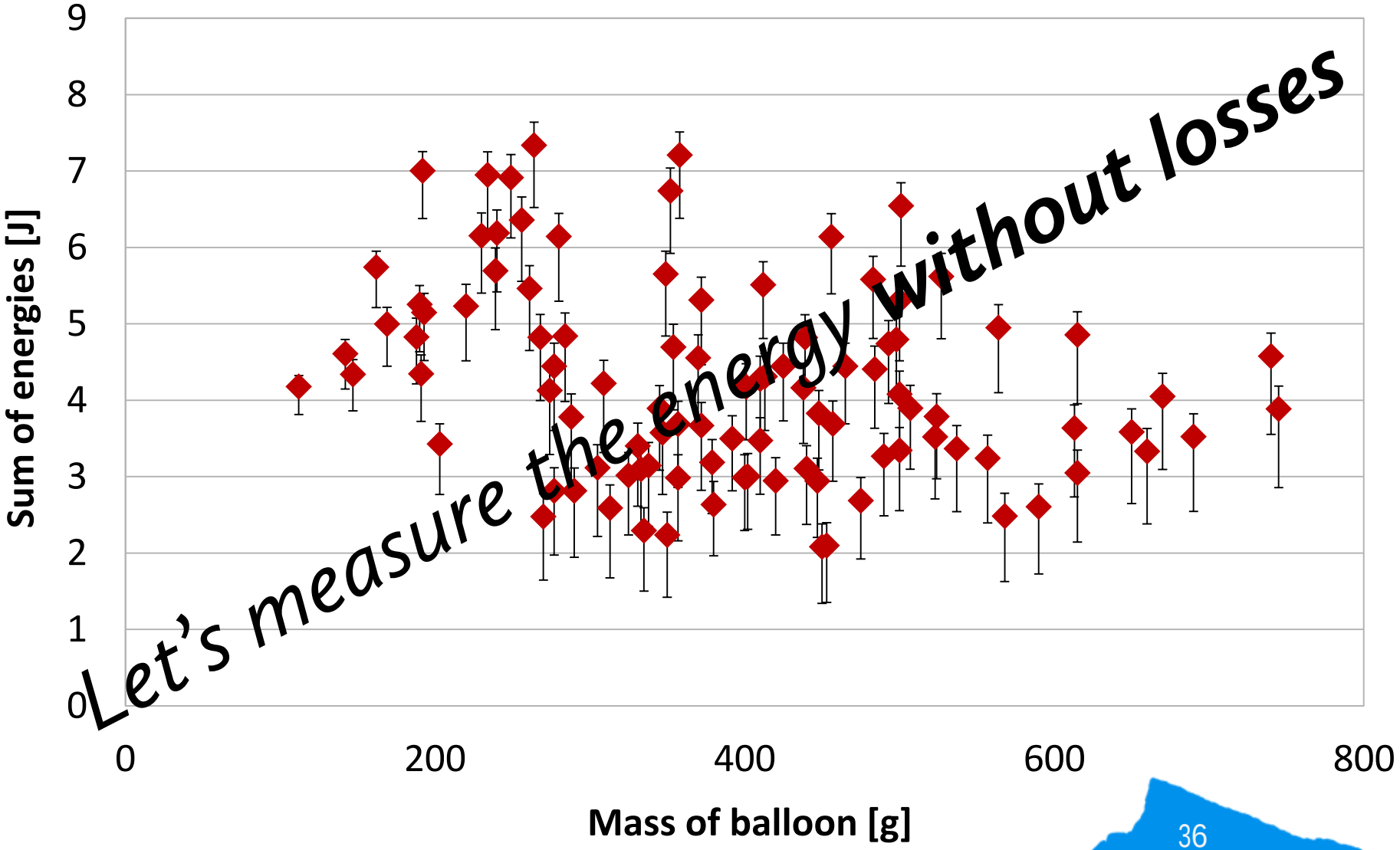
Elastic energy



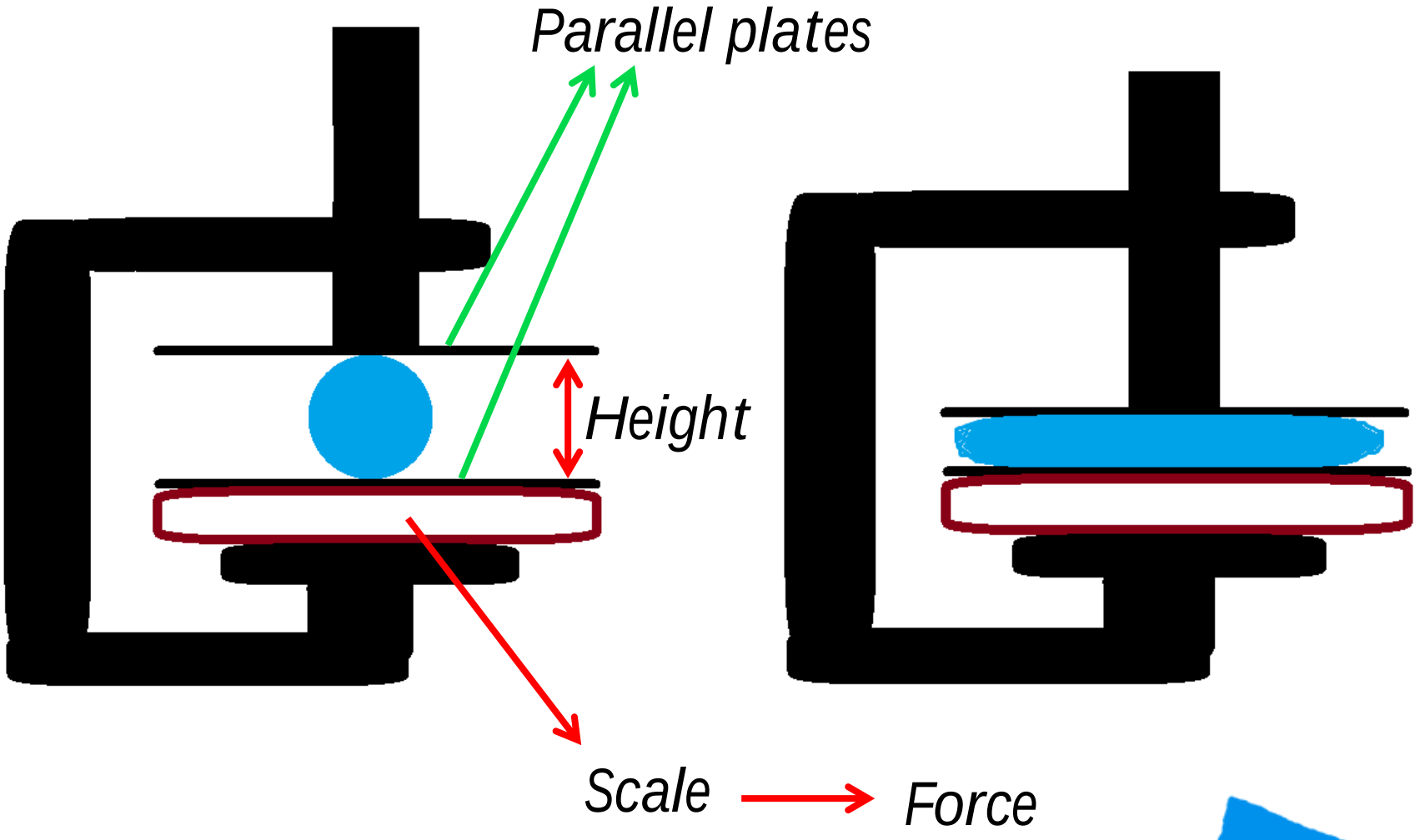
$$E_{total} = E_p + E_e$$

Total energy needed to burst

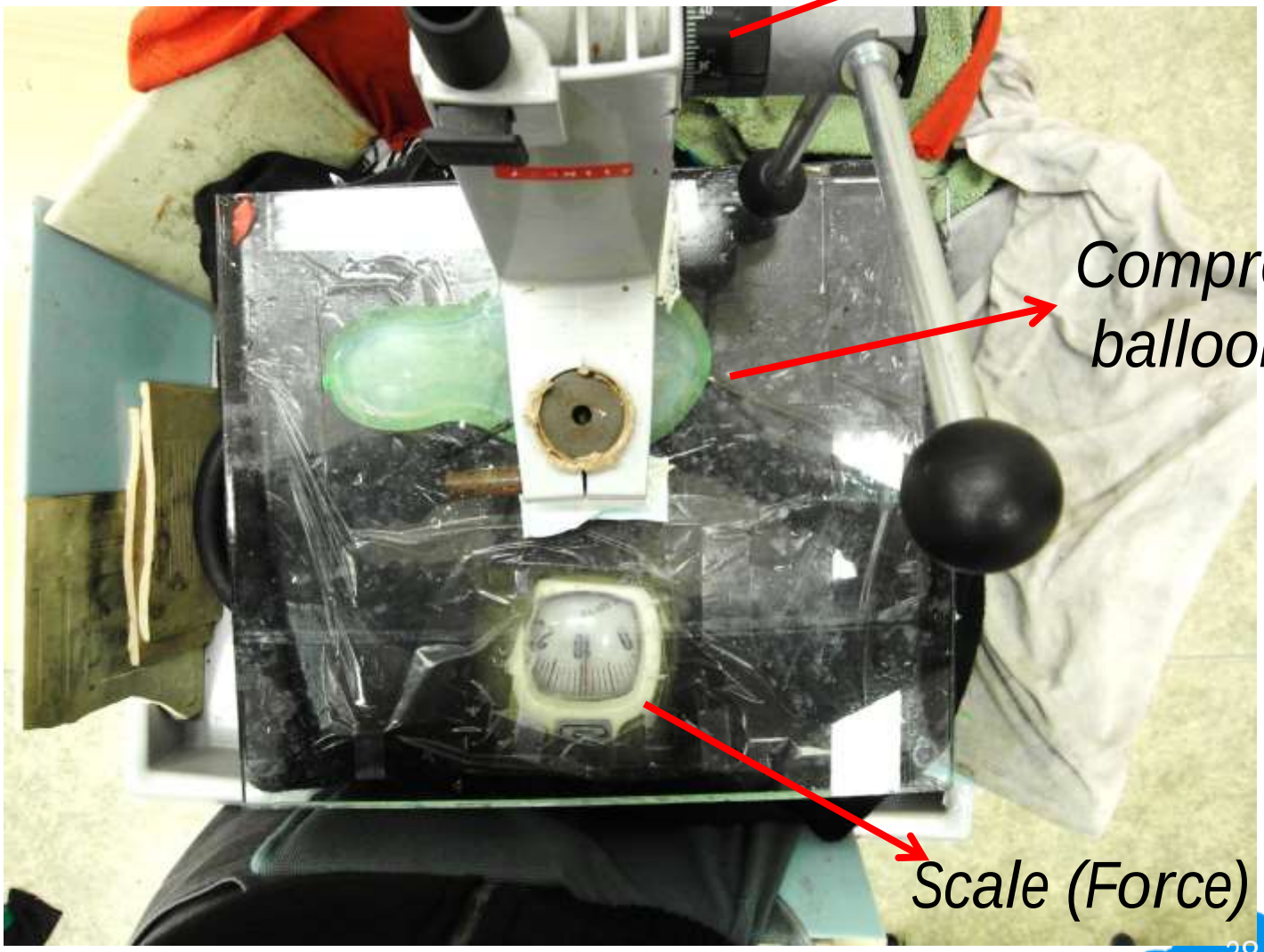
(Potential + Elastic)



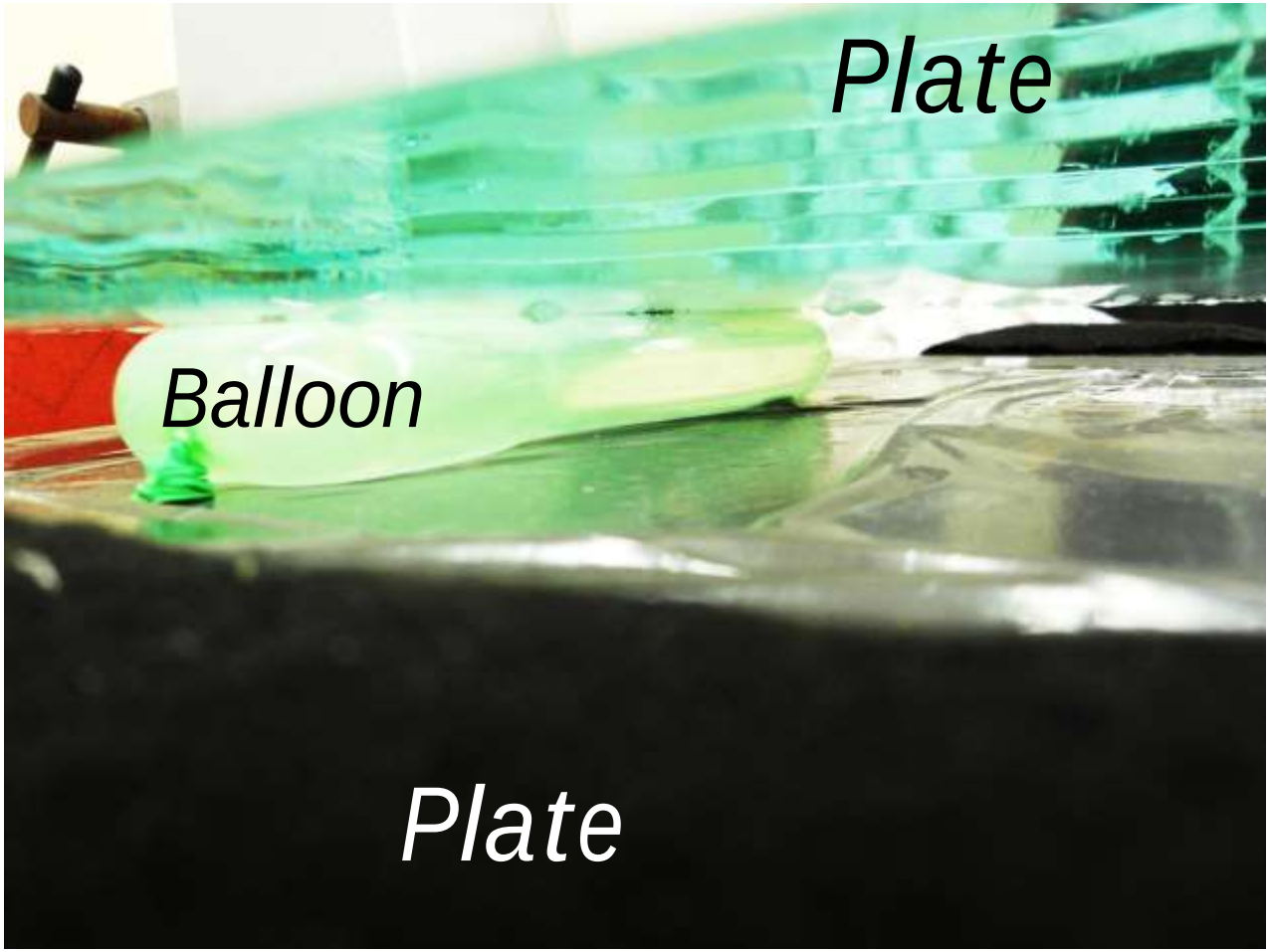
Compressing



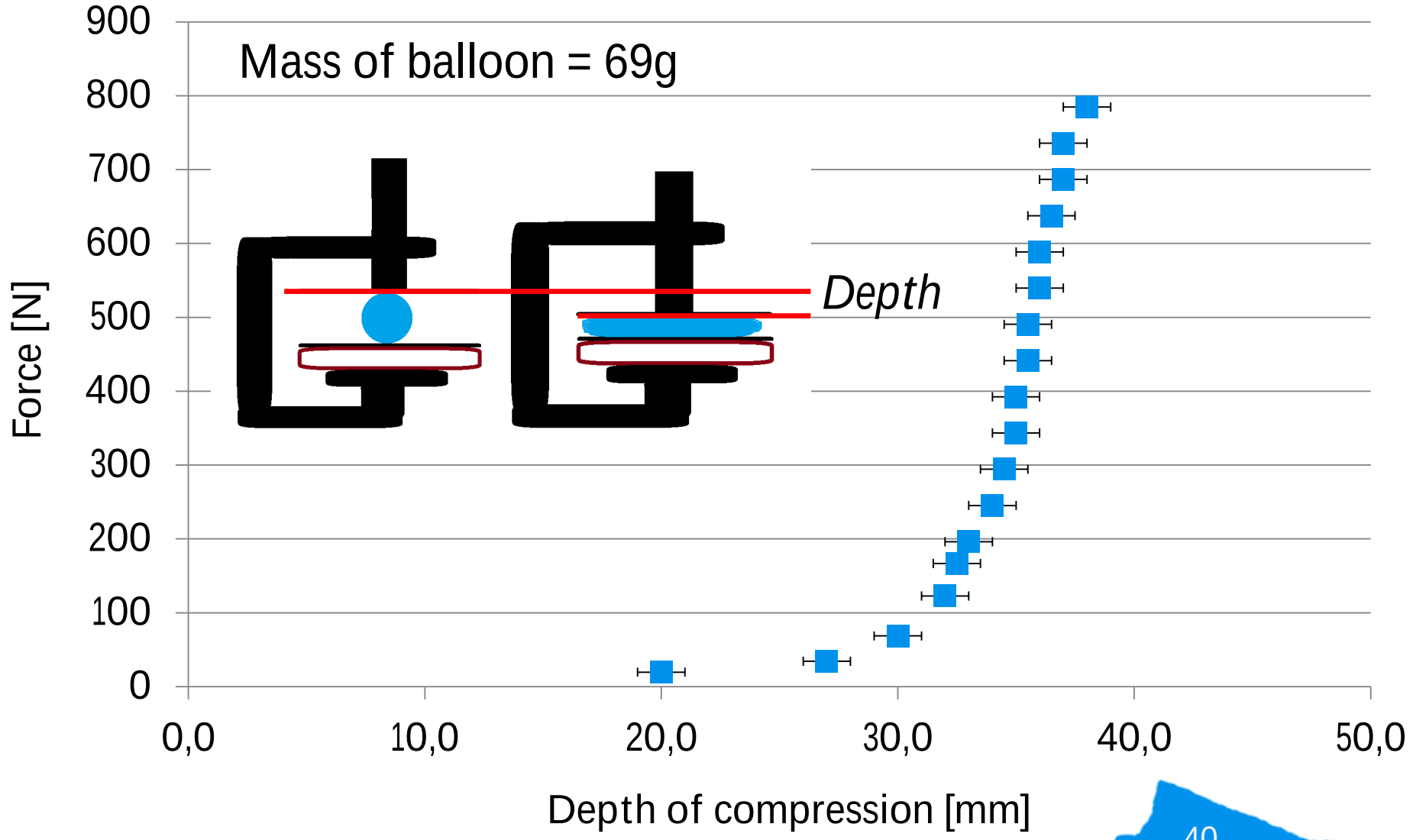
Apparatus



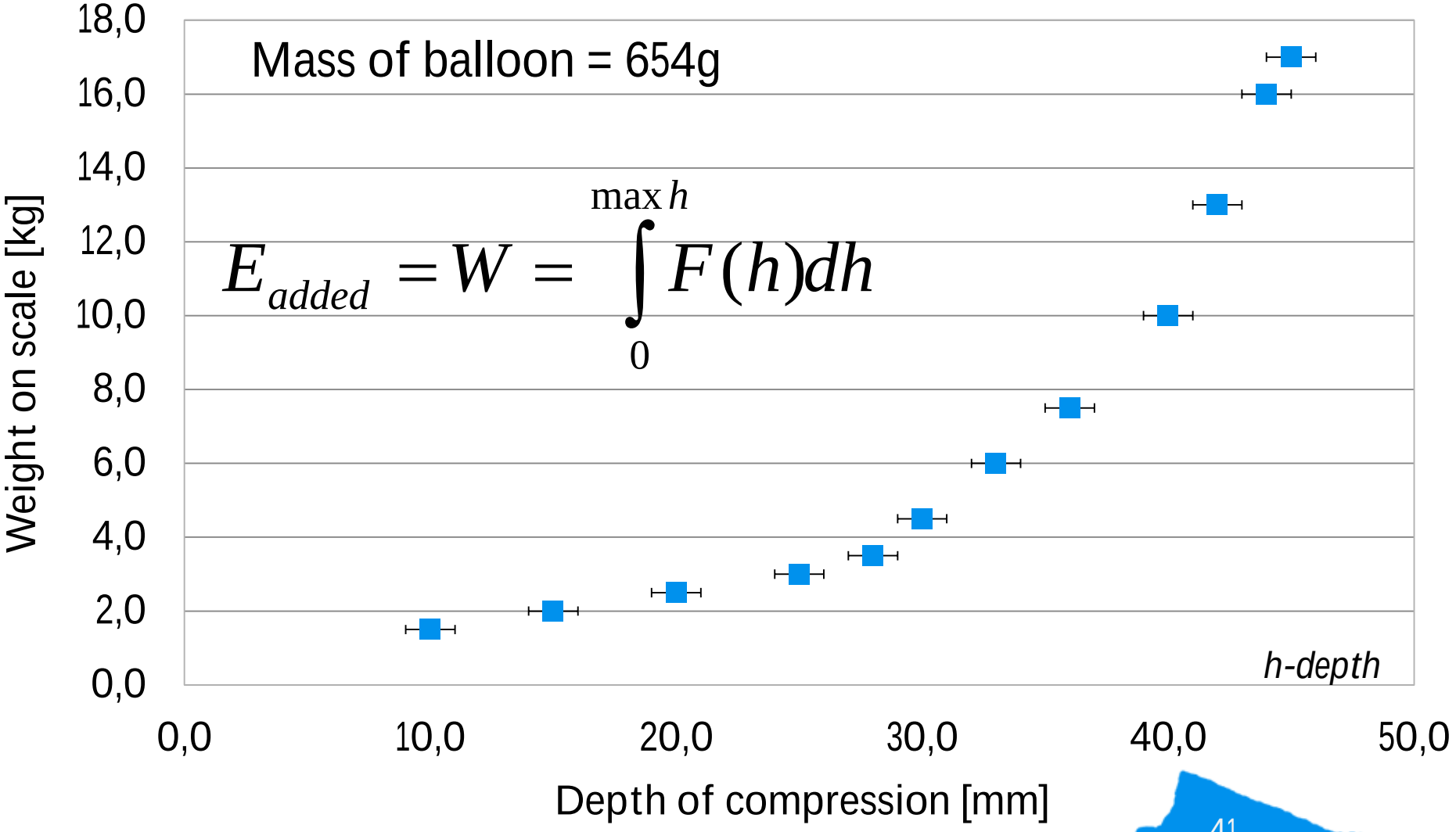
Compressed balloon



Force vs. depth of compression



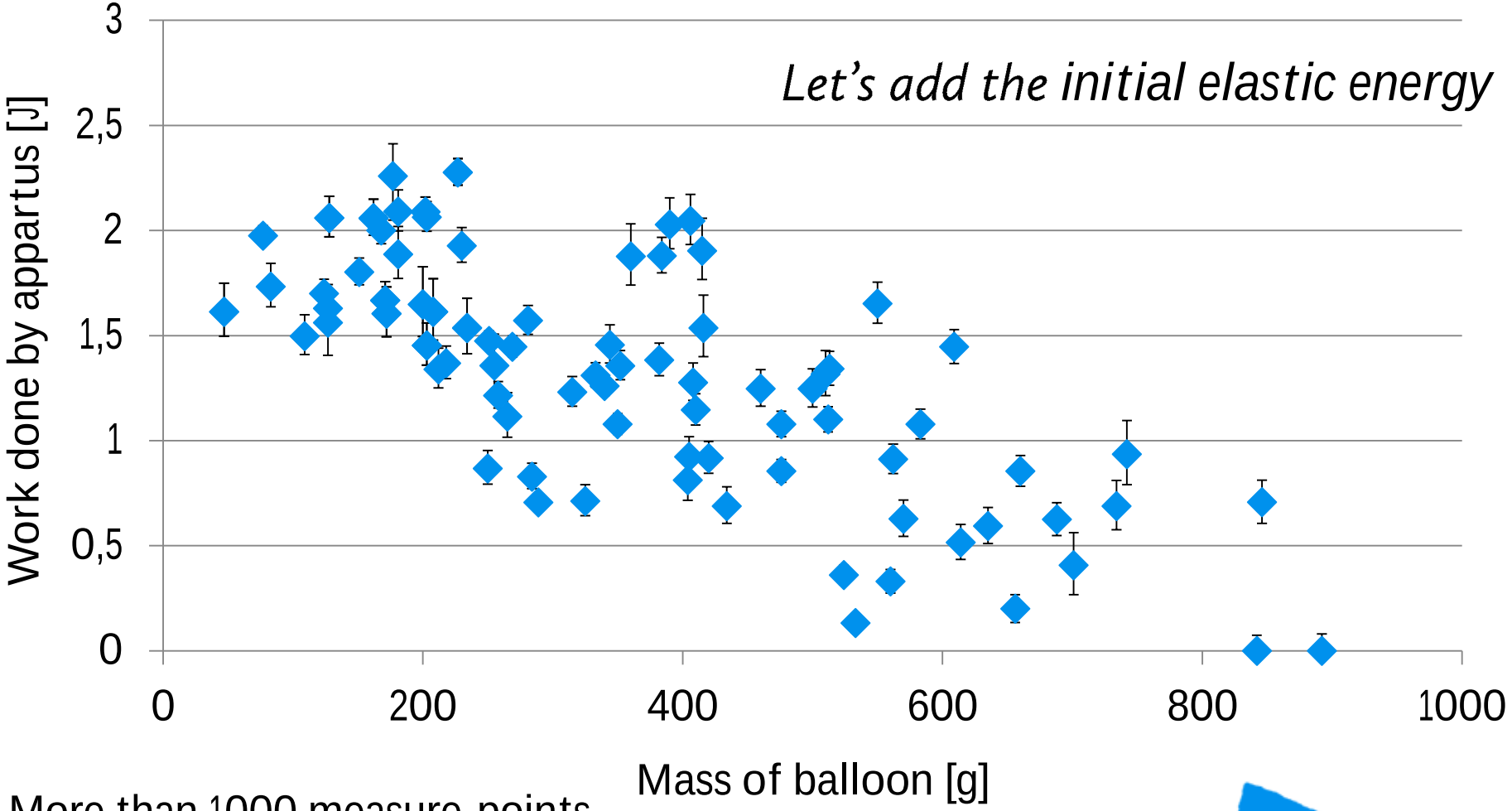
Force vs. depth of compression



Work done by apparatus

for many balloon volumes

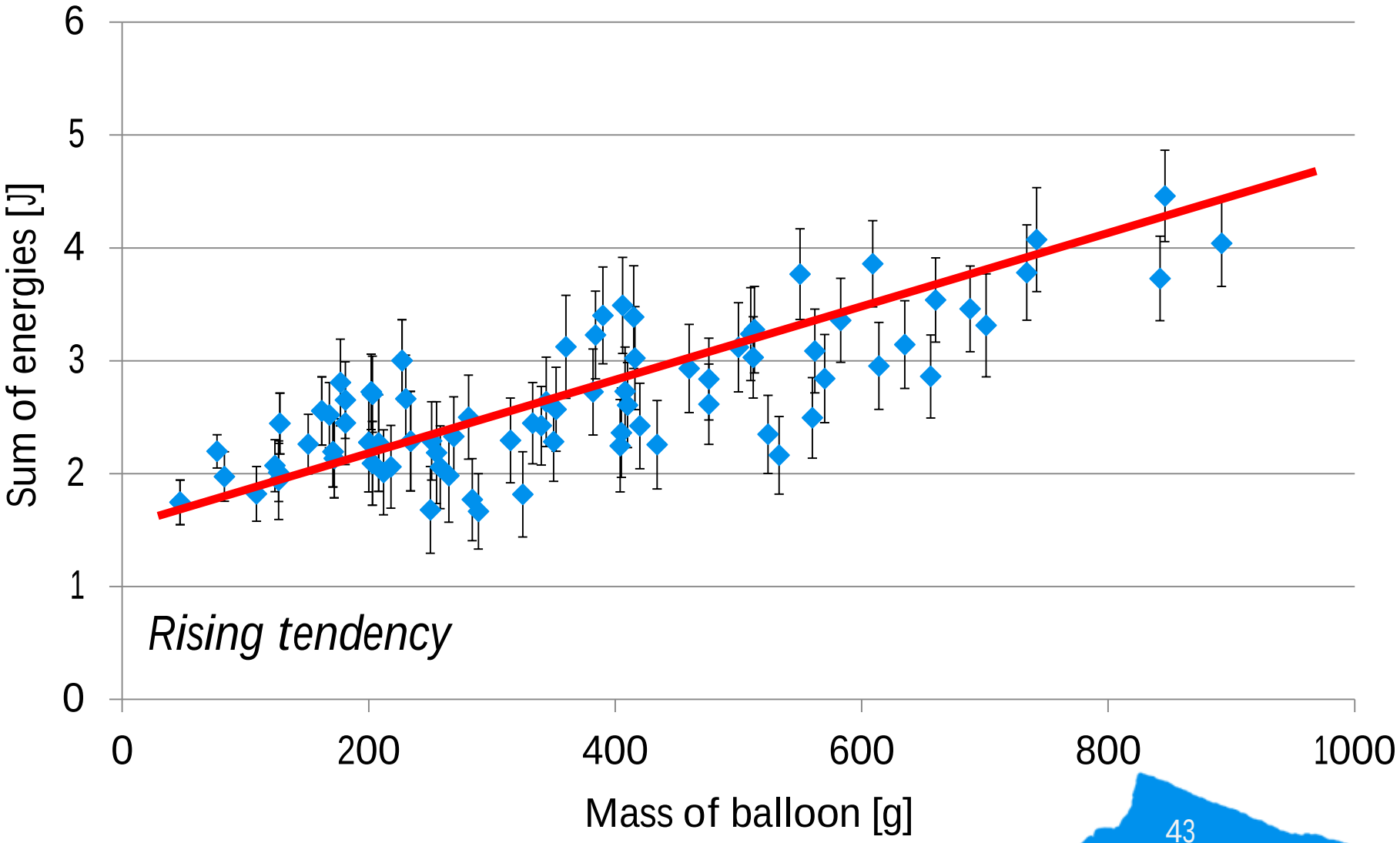
$$W = \int_0^{\max h} F(h)dh$$



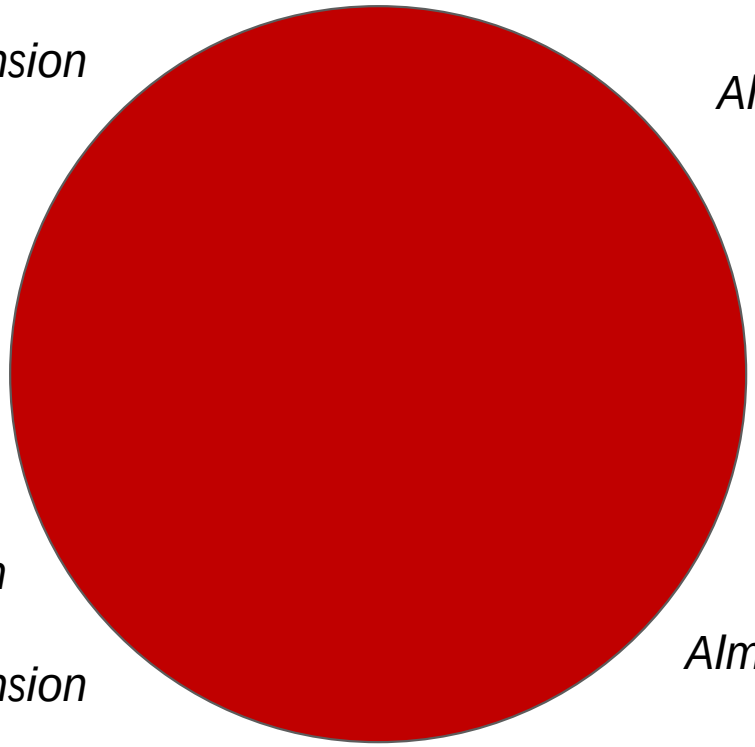
More than 1000 measure-points

Total energy needed for burst

(Work + Elastic)

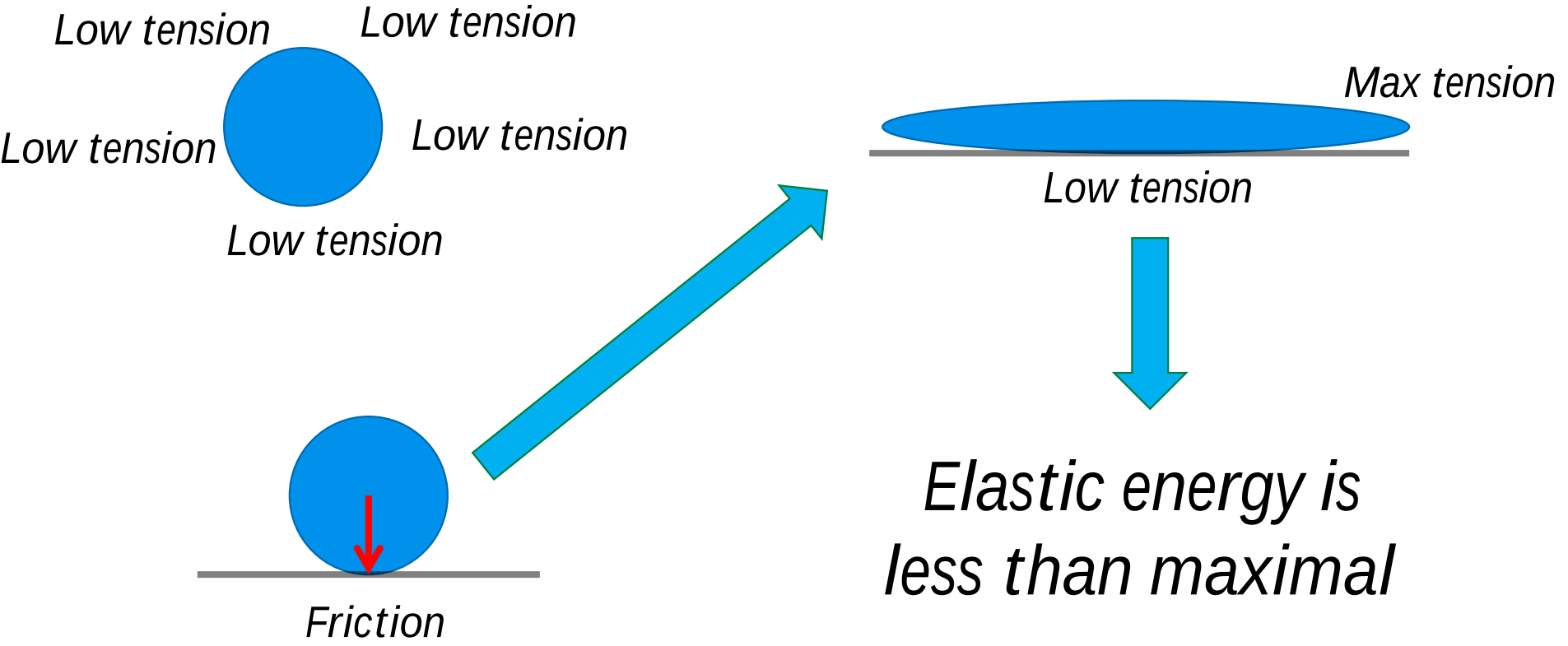


Big balloon



Elastic energy is almost maximal

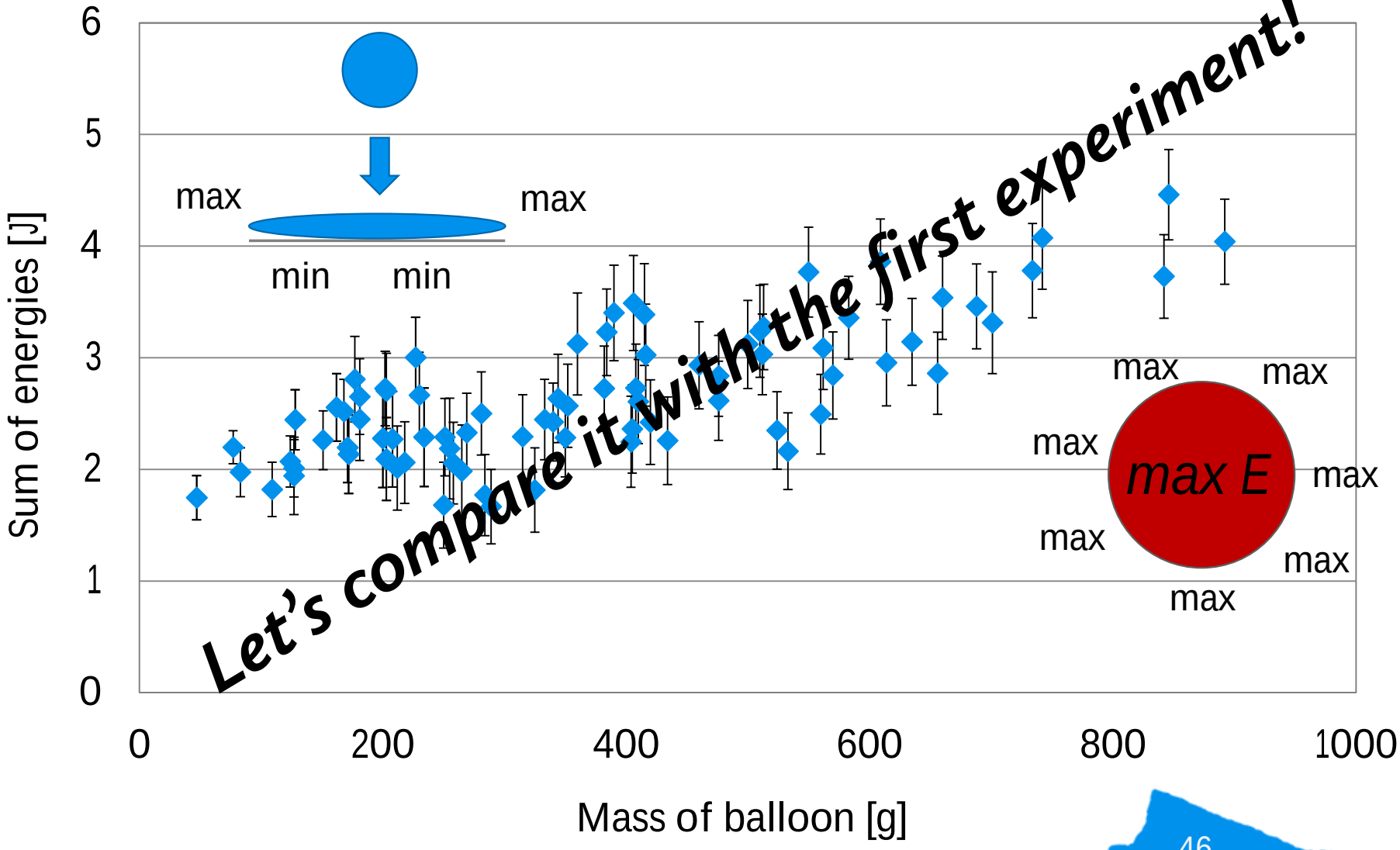
Small balloon



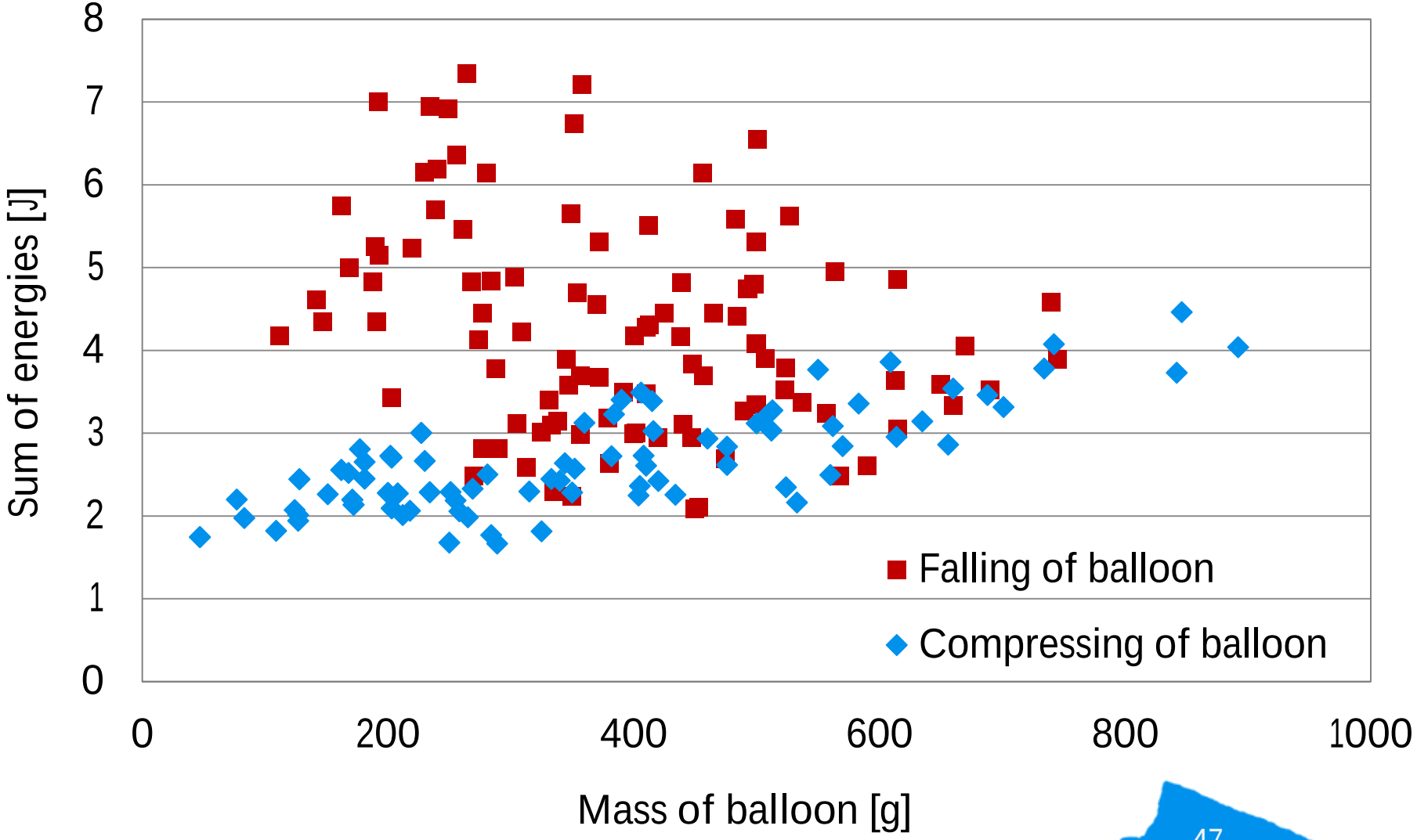
Tension at the bottom remains the same

Total energy needed for burst

(Work + Elastic)



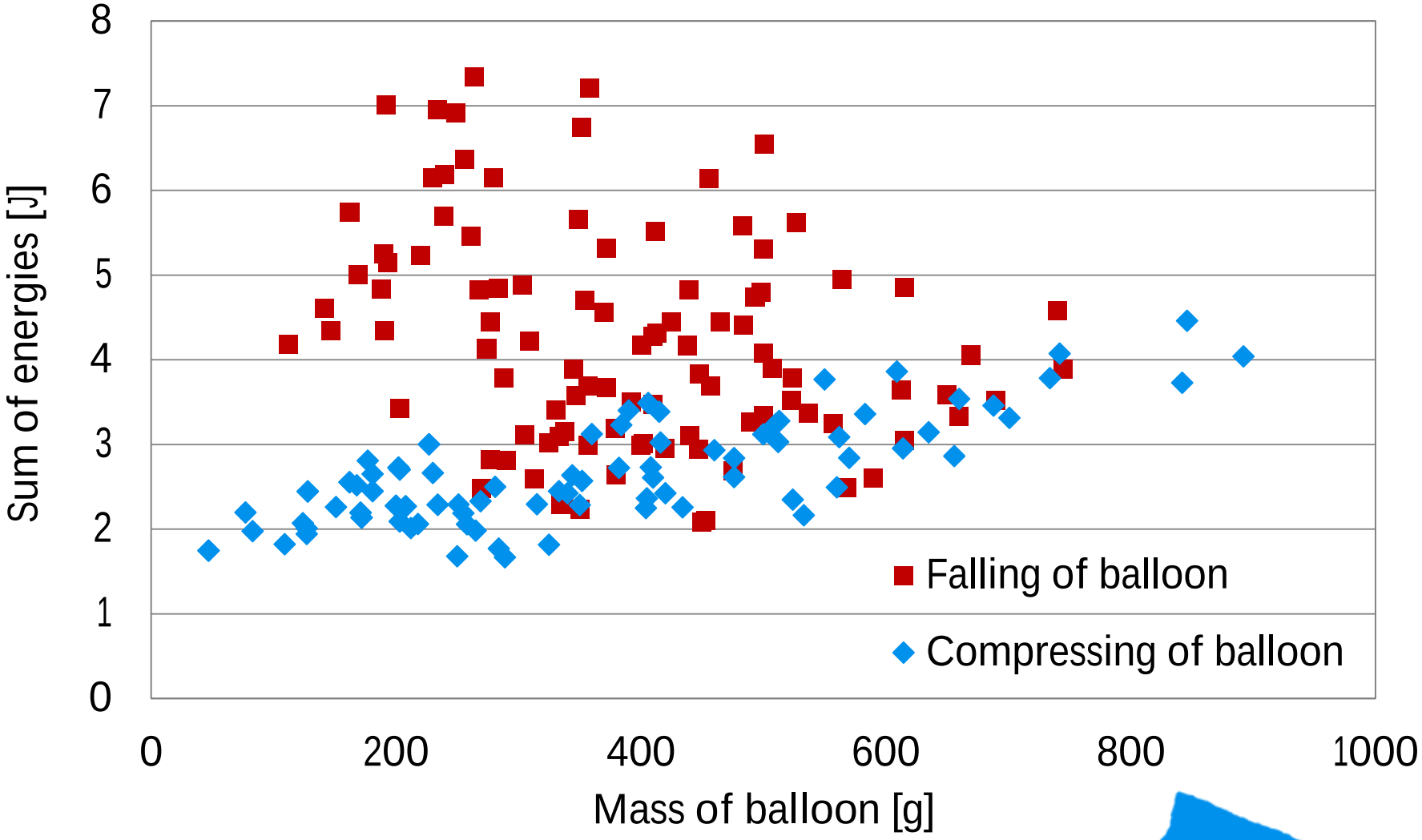
Energy needed to burst trough fall & through compression



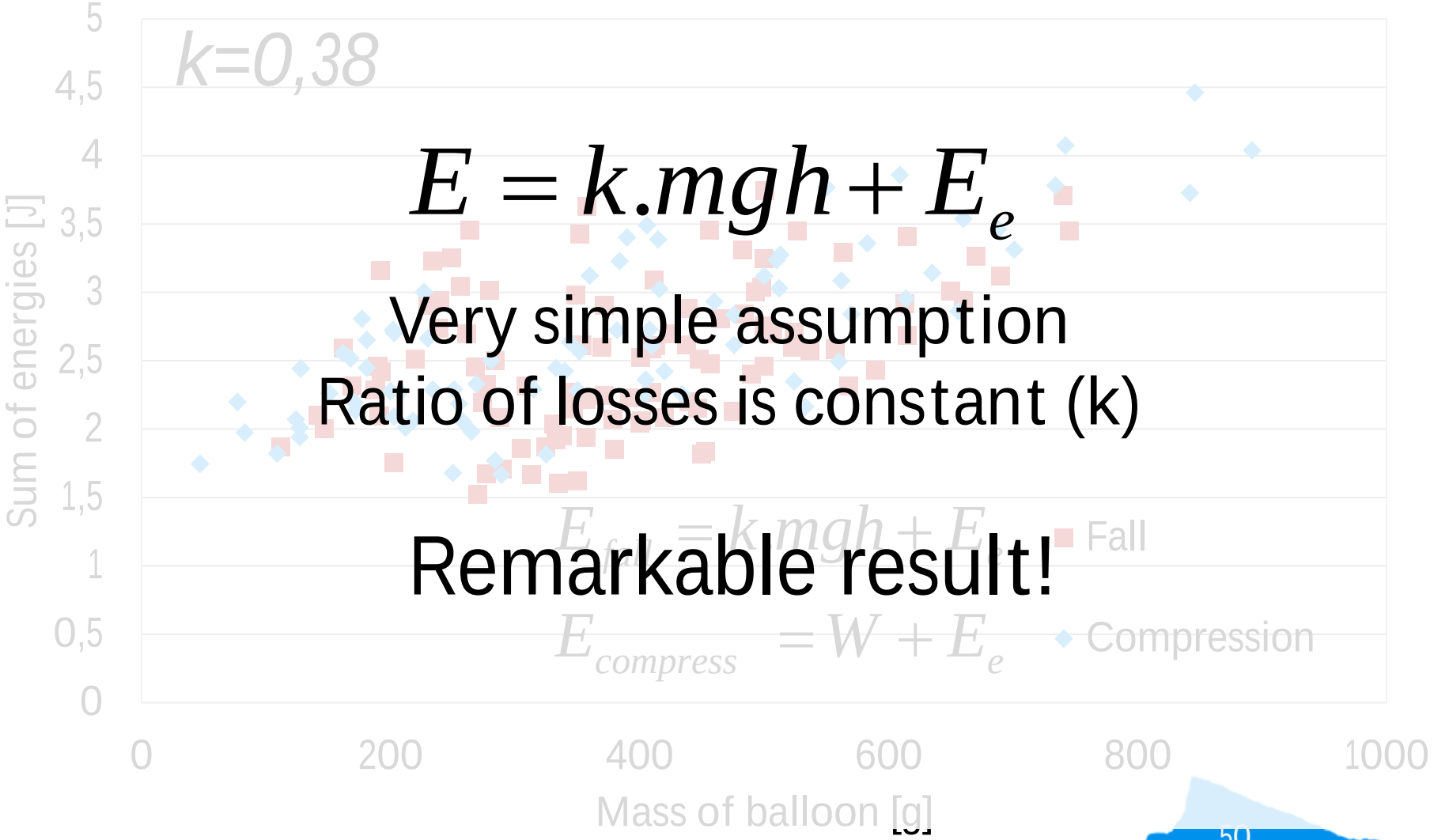
Falling balloon

In graph	In real life
$E = E_p + E_e$	There are losses Water convection Heat Let's assume that constant ratio of energy is preserved
$E = mgh + E_e$	$E = k.mgh + E_e$

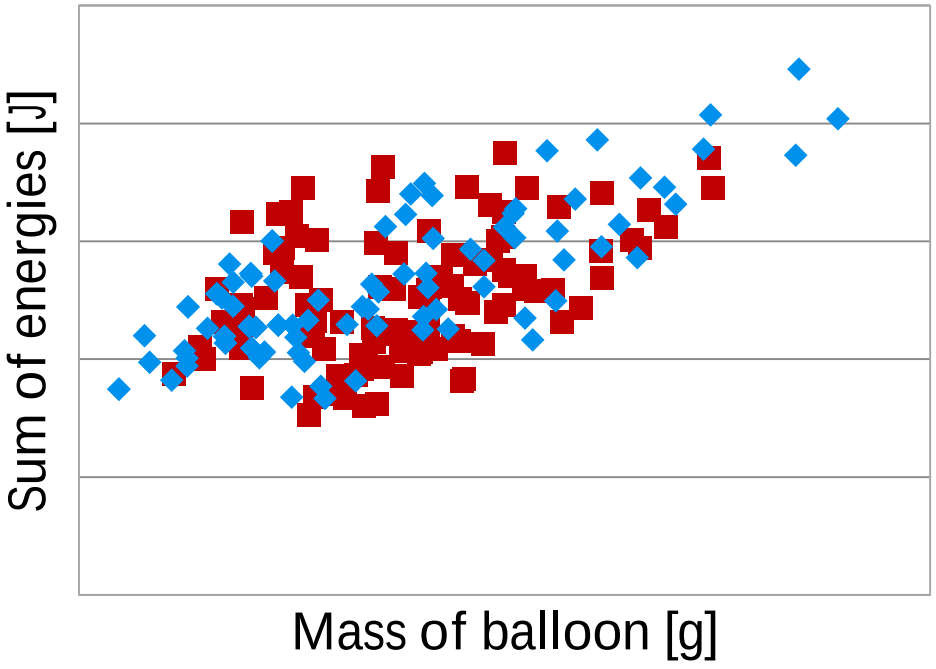
Energy needed to burst trough fall & through compression

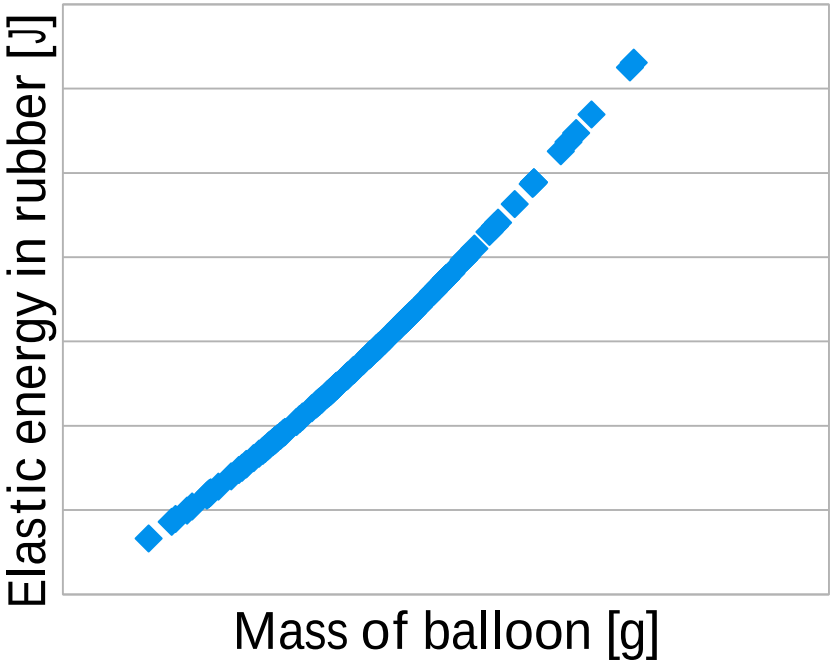


Energy needed to burst trough fall & through compression



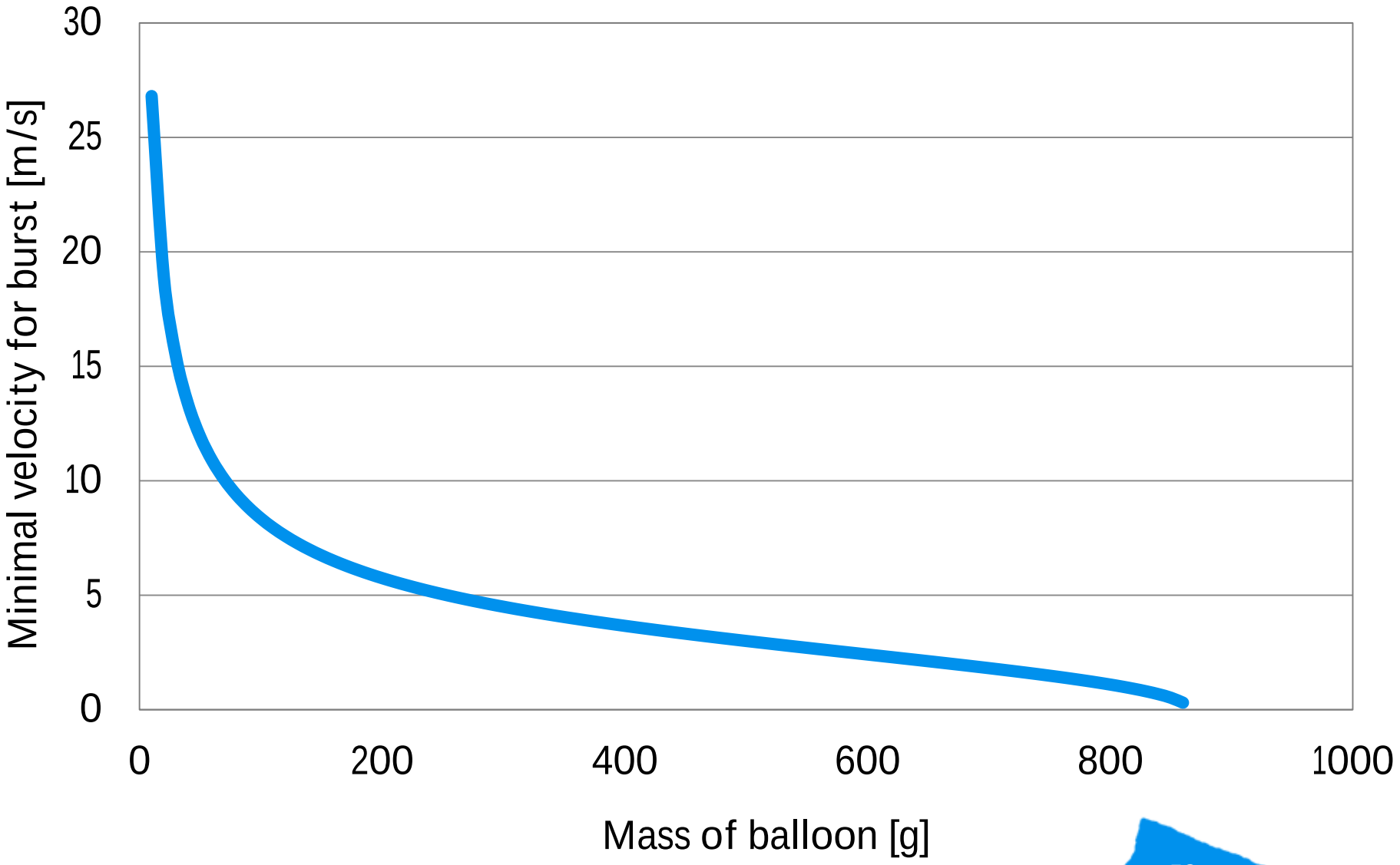
What we have





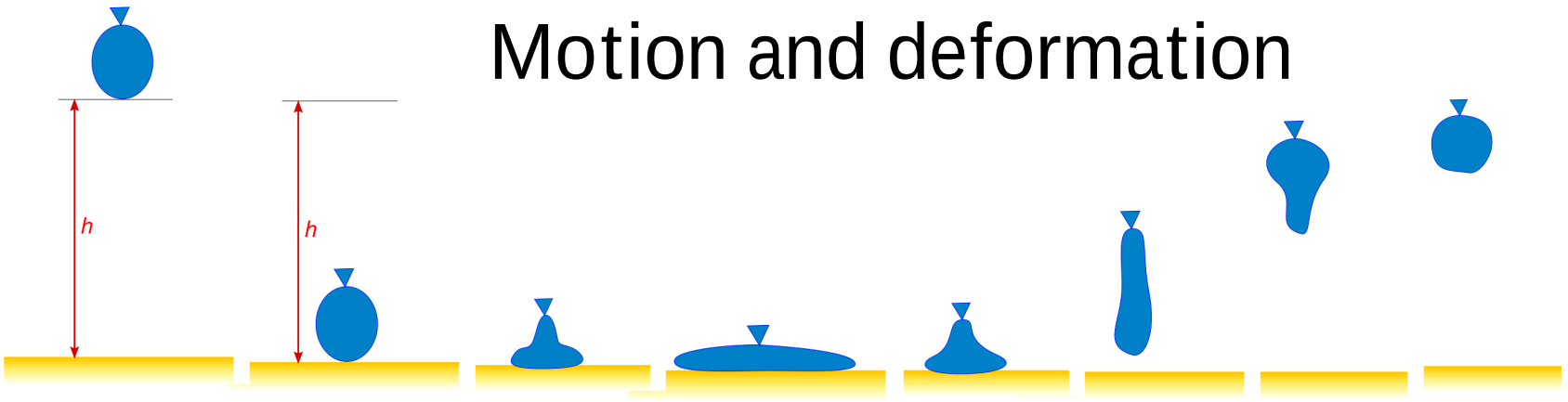
We can derive approximately the velocity of throw needed to burst a balloon

Approximate velocity needed for burst



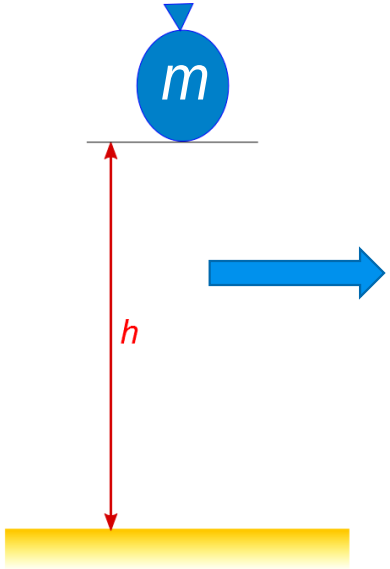
Summary

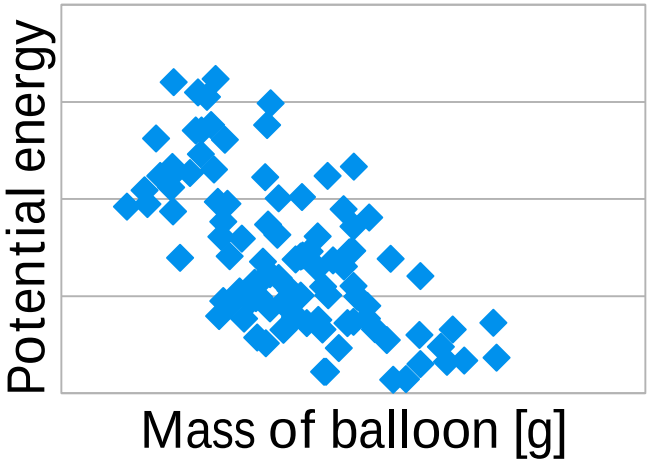
Motion and deformation

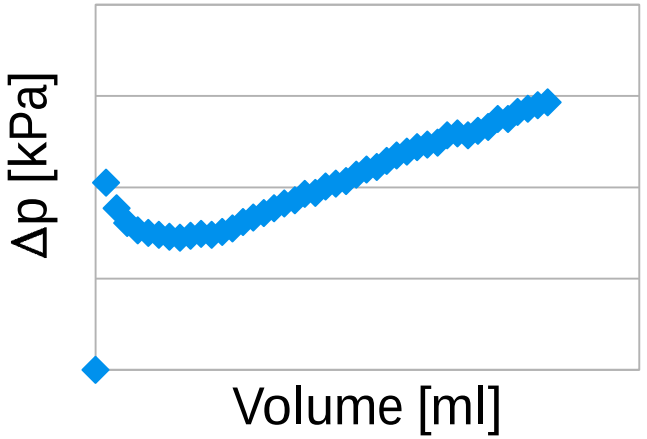


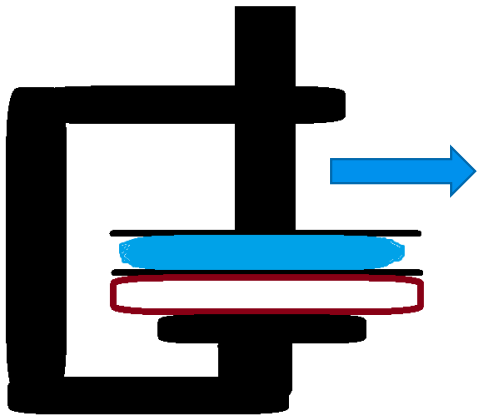
Rebound

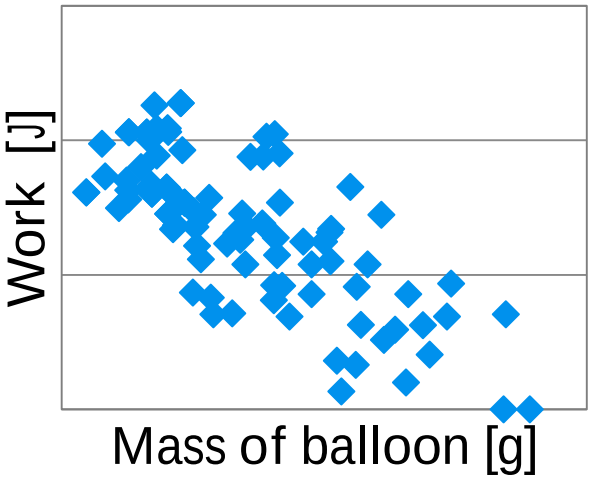
Summary - Burst

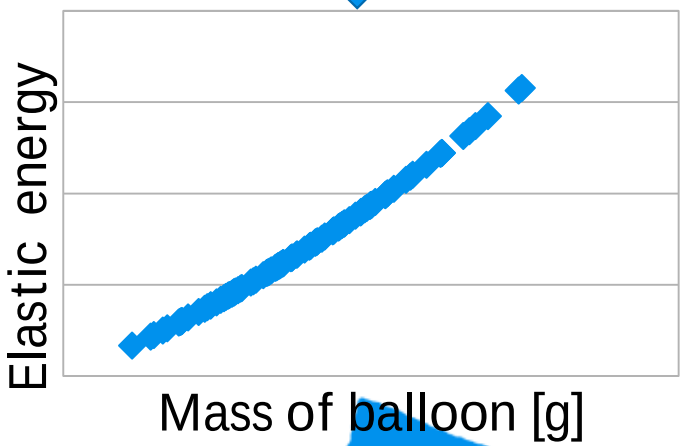




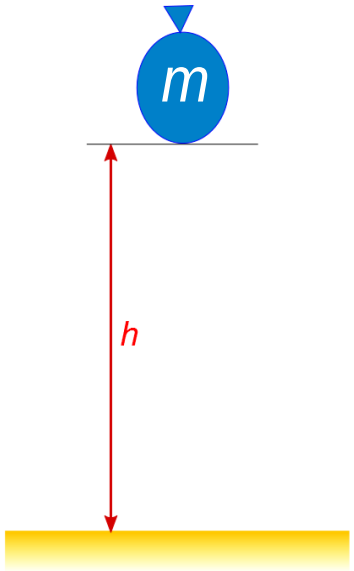


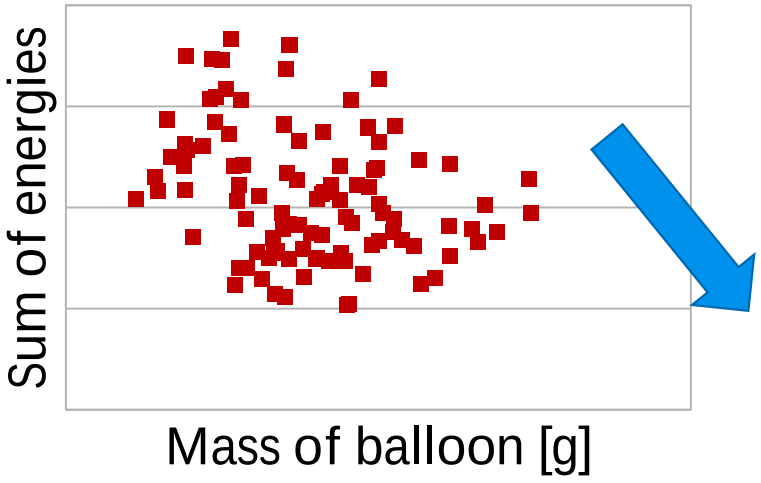




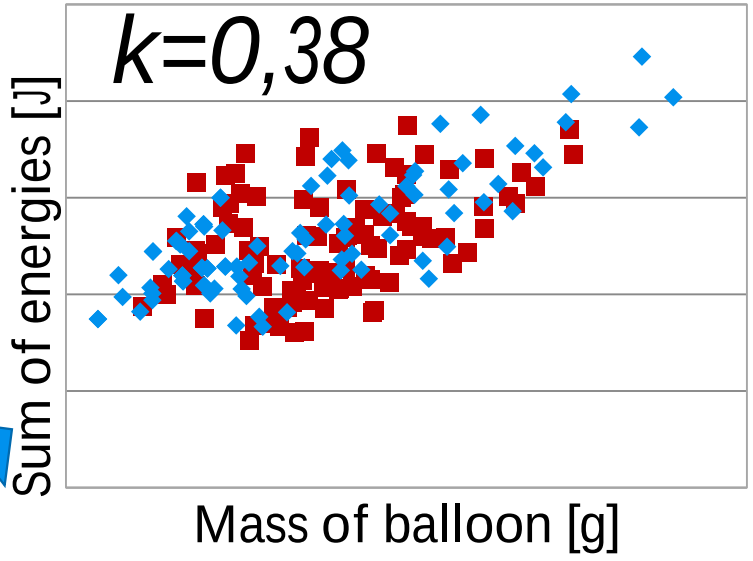


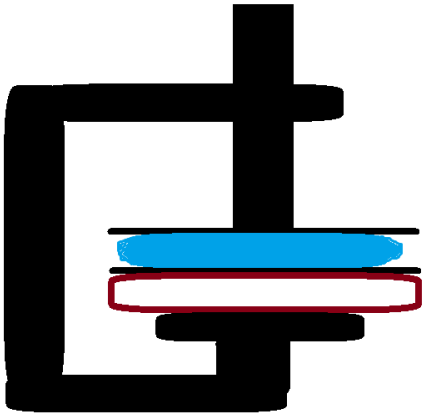
Summary - Burst

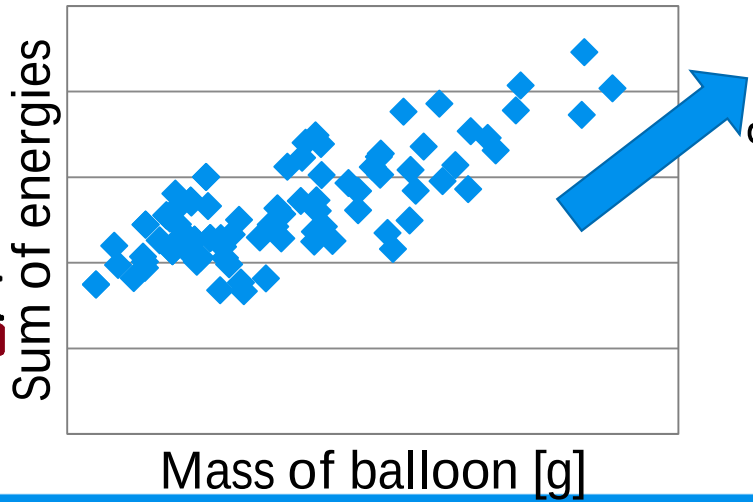




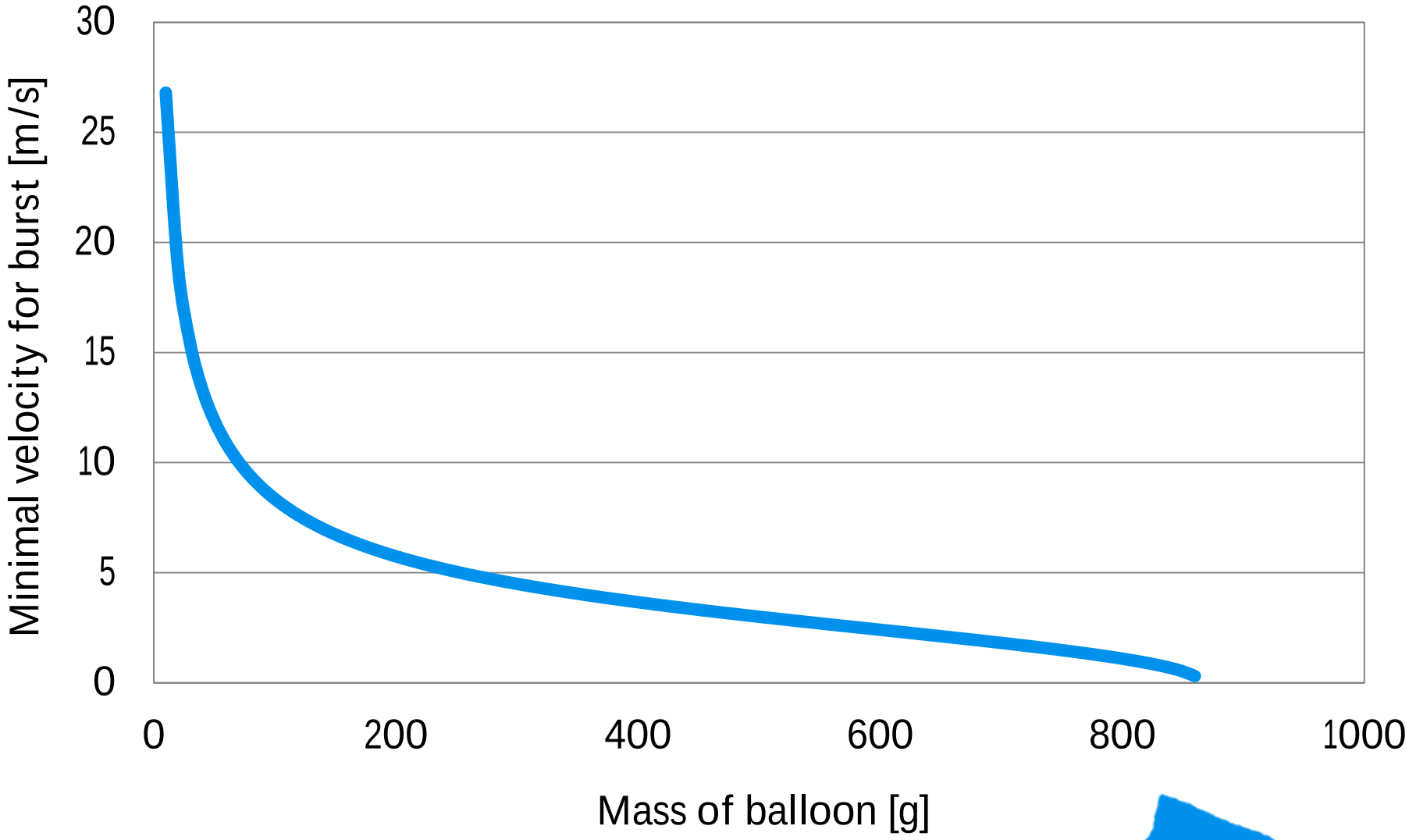
$$E_{total} = kE_p + E_e$$





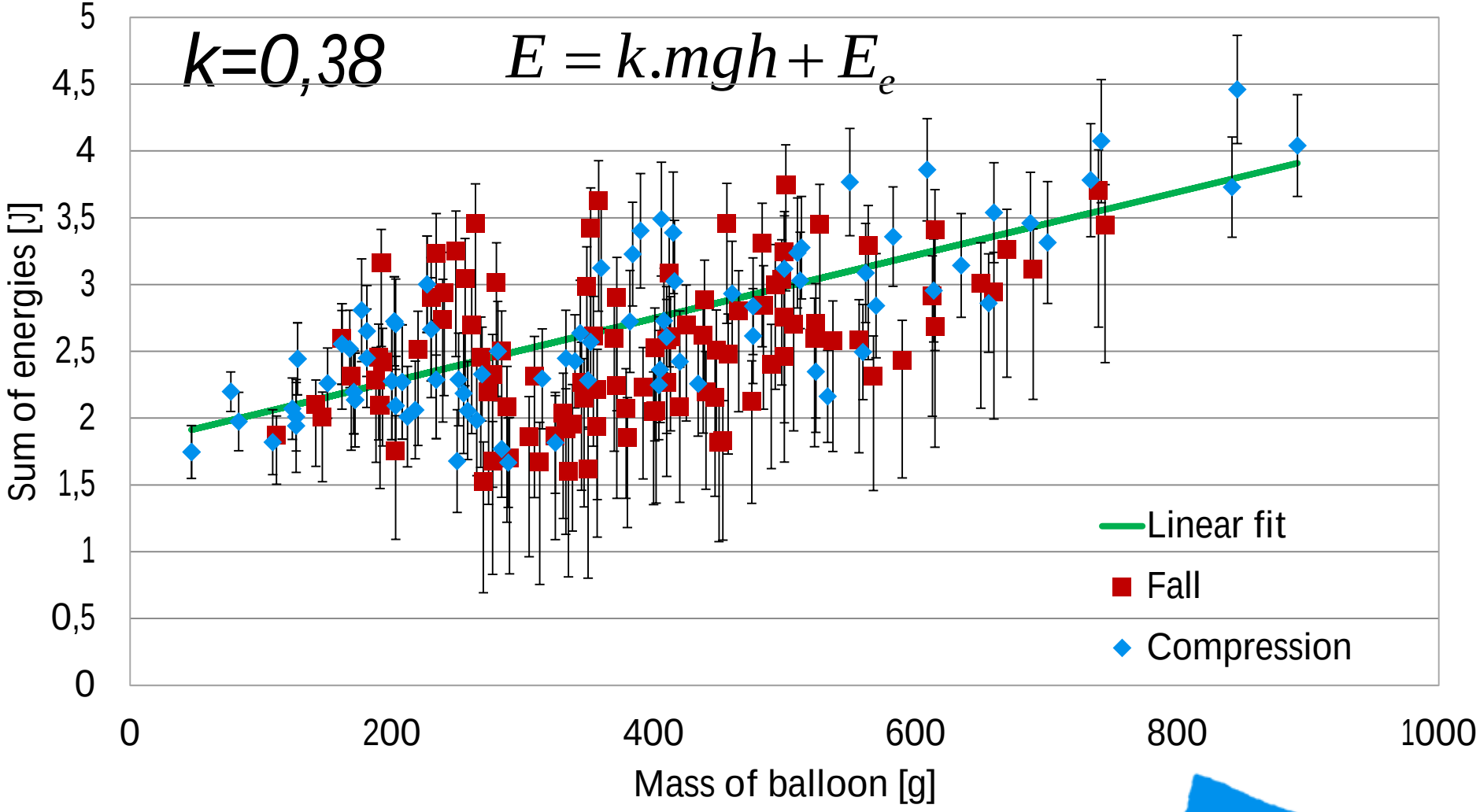


Thank you for your attention!



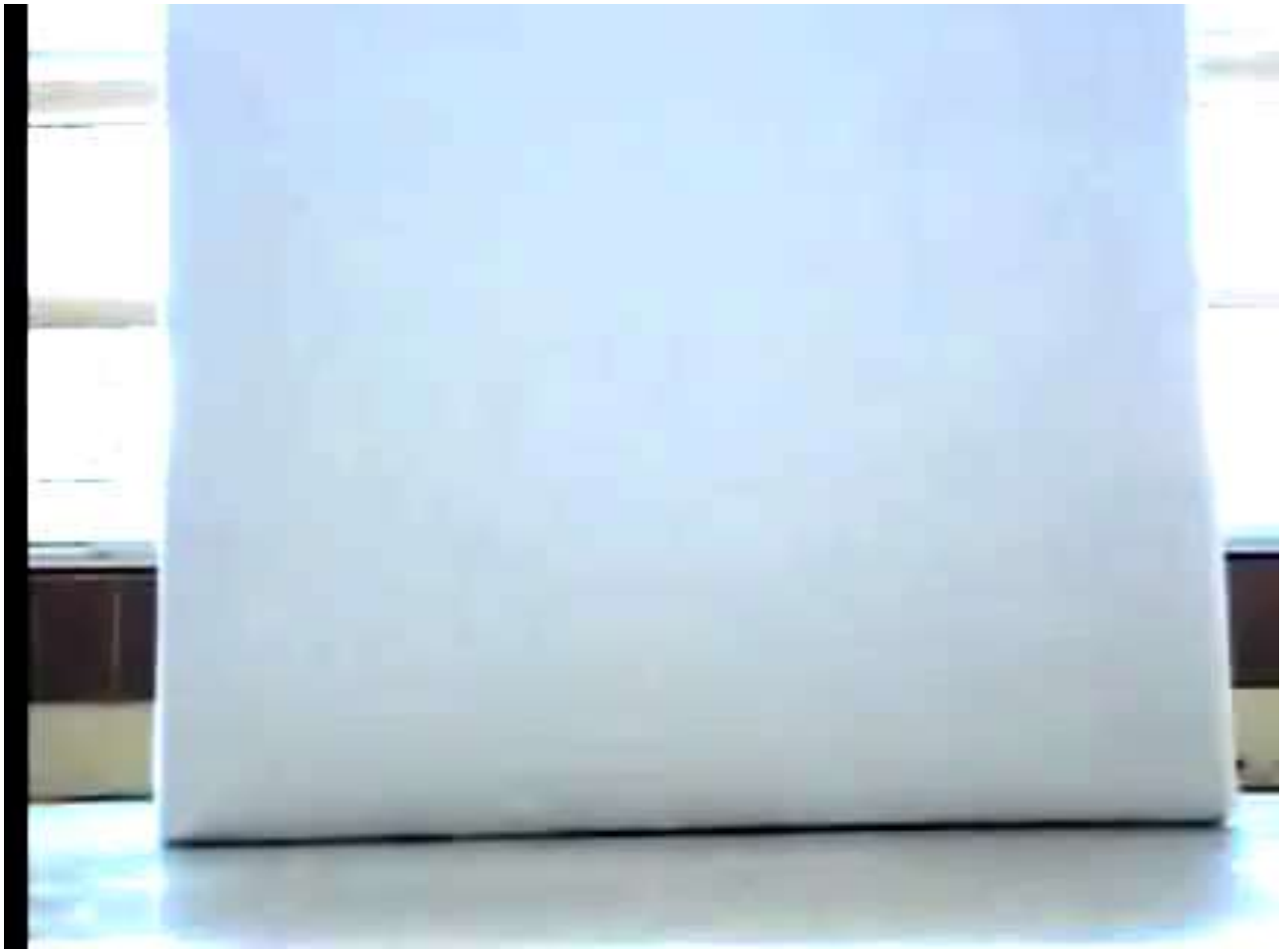
APPENDICES

Energy needed to burst trough fall & through compression

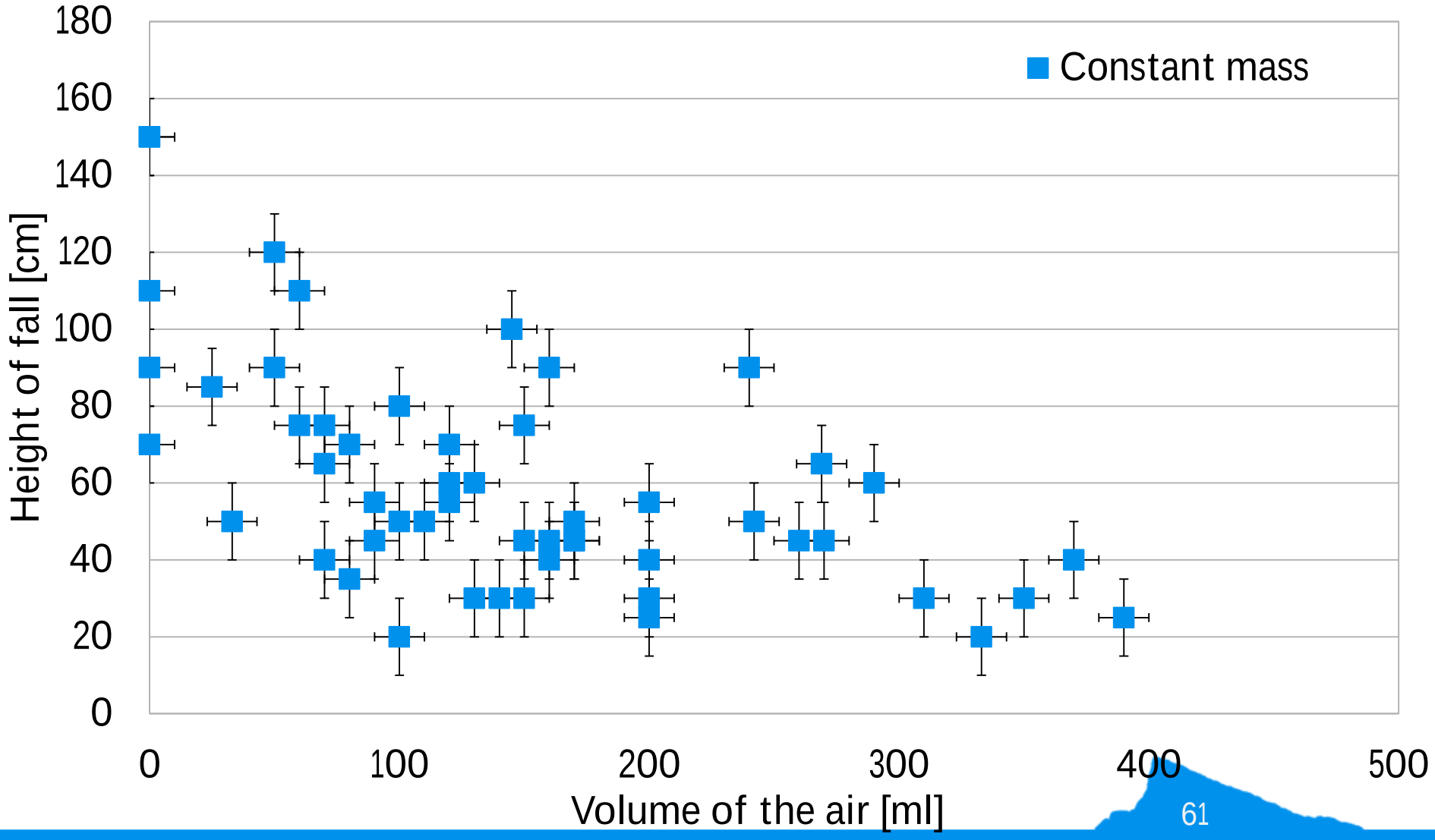


Rubber stretch at rebound

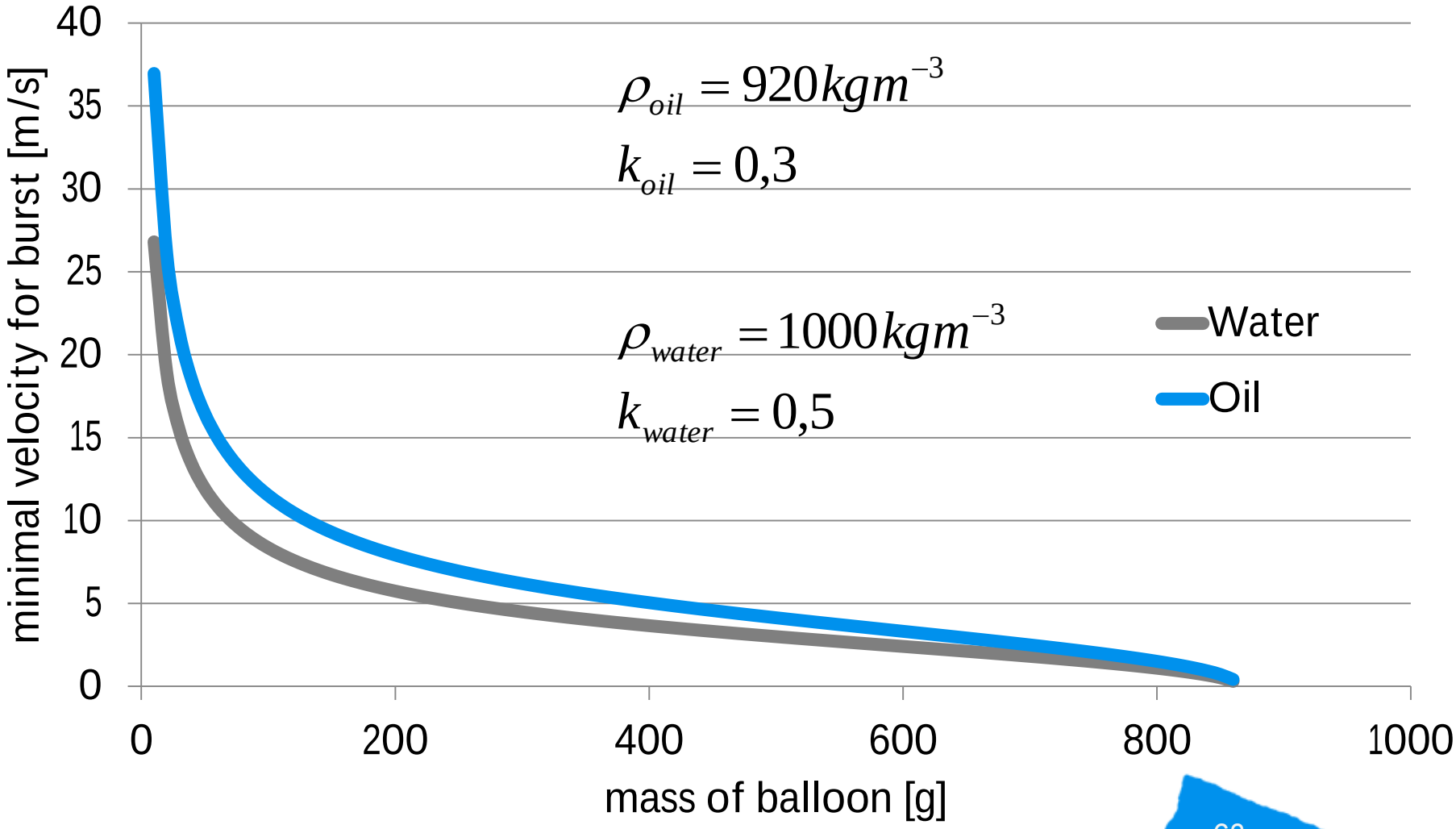
Rubber stretch at rebound



Adding air


Constant mass
Height of fall [cm]
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
500
Volume of the air [ml]

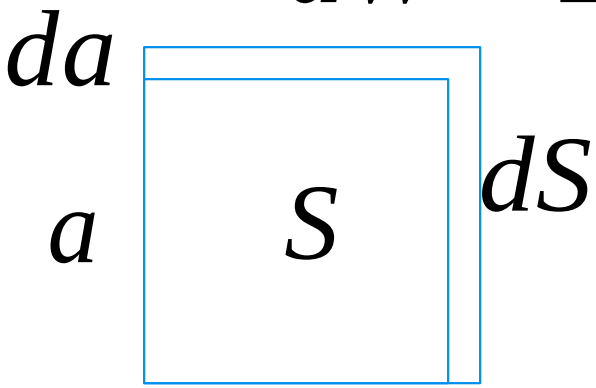
Other liquid



Elastic energy of the balloon

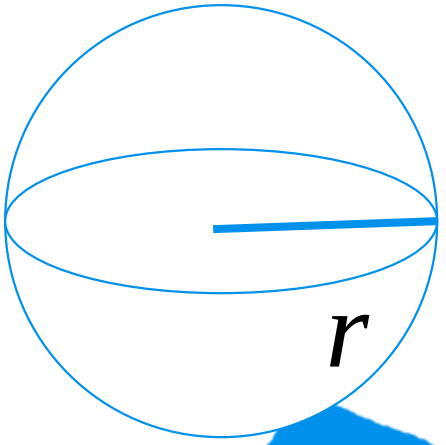
- Stretching a piece of rubber, surface tension σ

$$dW = 2a\sigma da = \sigma dS$$



- In terms of pressure inside:

$$p = \frac{2\pi r\sigma}{\pi r^2} \qquad \sigma = \frac{rp}{2}$$



- Spherical shape: $S = 4\pi r^2 \quad dS = 8\pi r dr$

$$V = \frac{4}{3}\pi r^3 \quad dV = 4\pi r^2 dr$$

$$dW = \frac{pr}{2} dS = p4\pi r^2 dr = pdV$$

- Elastic energy $= \int pdV$