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.

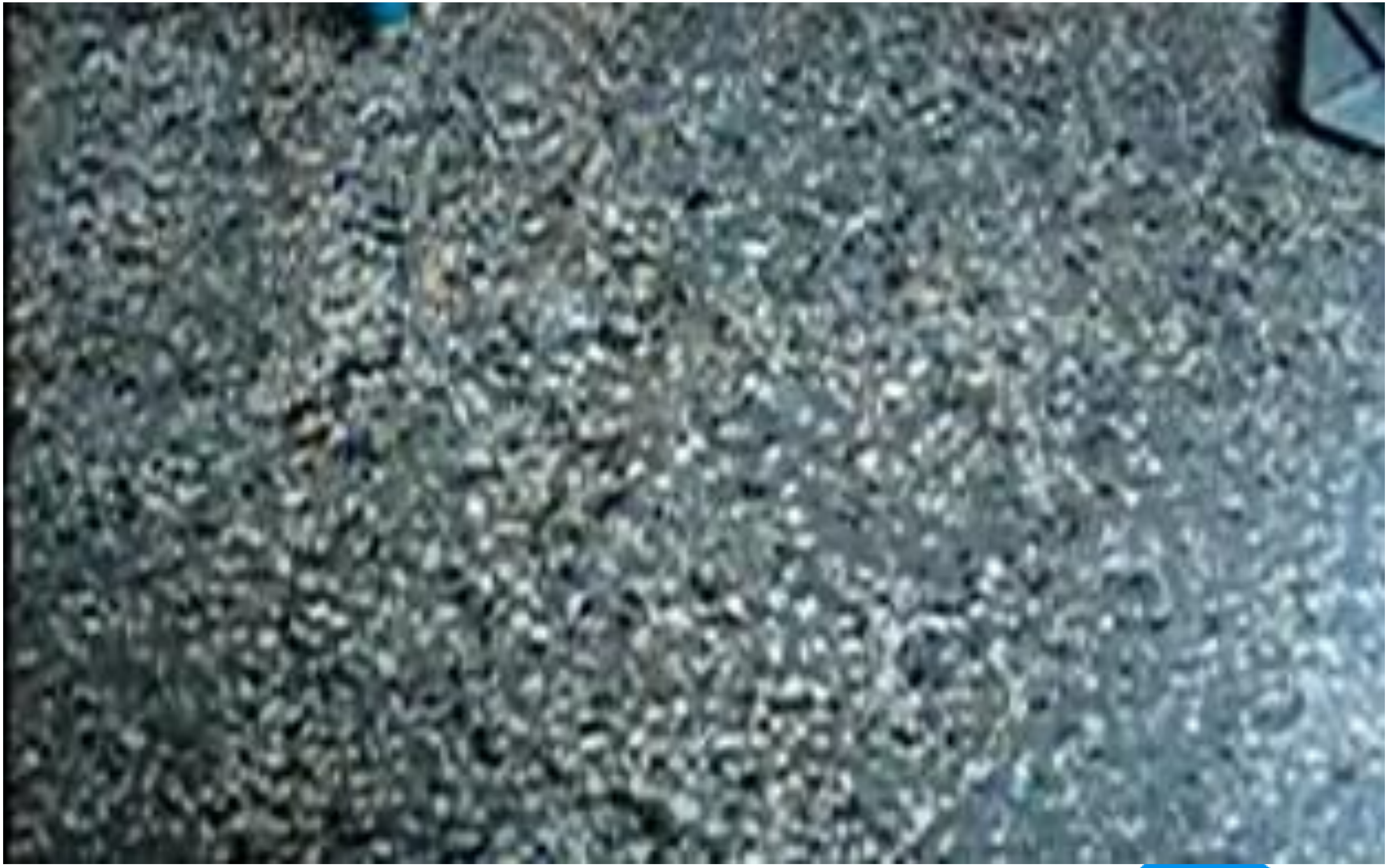
Under what circumstances does the balloon **burst**?

Content

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

How it looks

How it looks

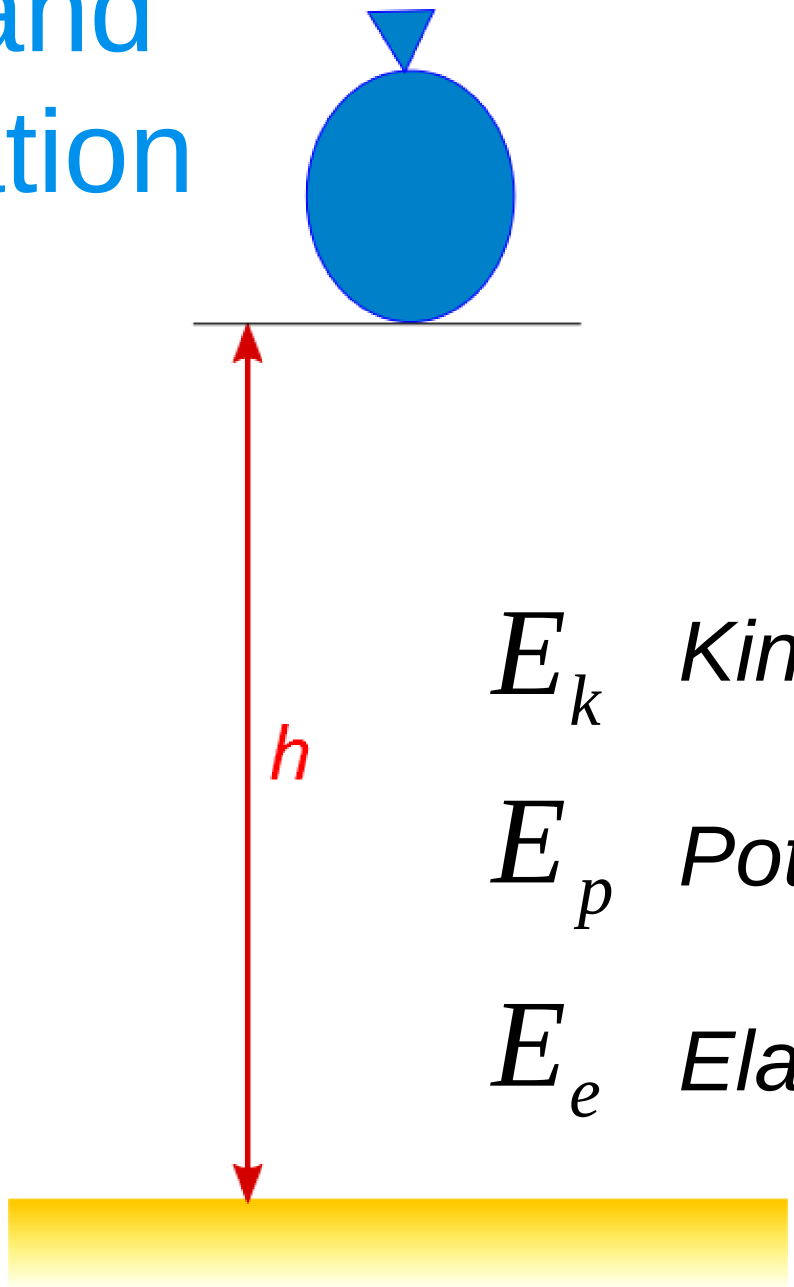


Motion and deformation

$$E_k = 0$$

$$E_p = mgh$$

$$E_e = A$$



E_k *Kinetic energy*

E_p *Potential energy*

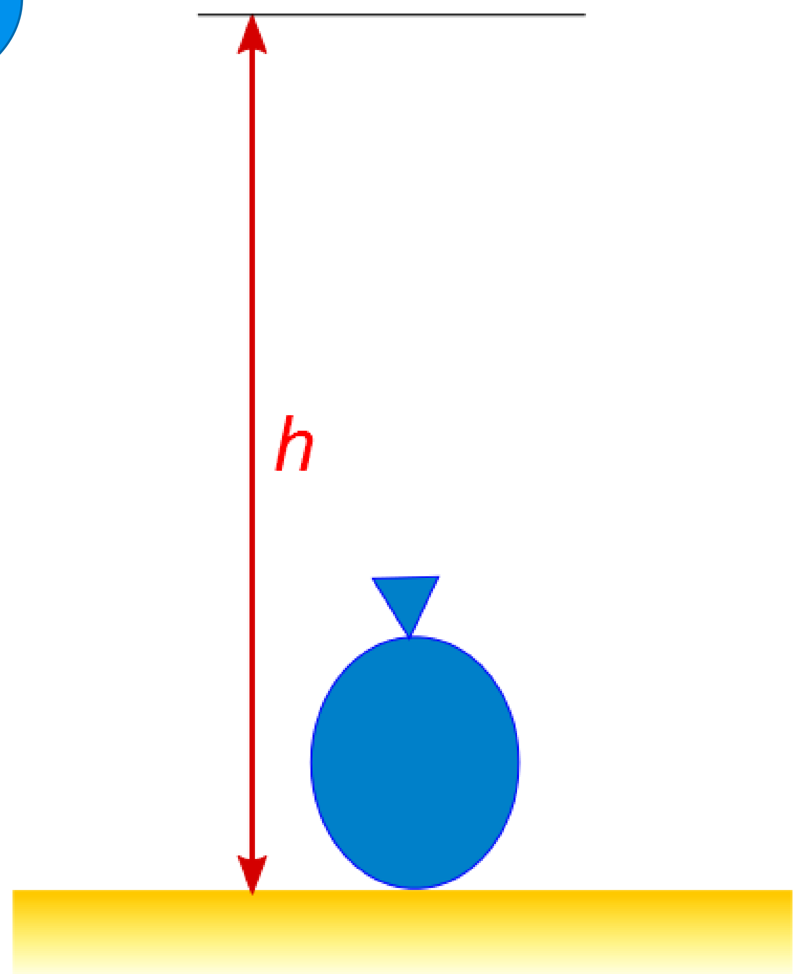
E_e *Elastic energy*

Motion and deformation

$$E_k = mgh$$

$$E_p = 0$$

$$E_e = A$$



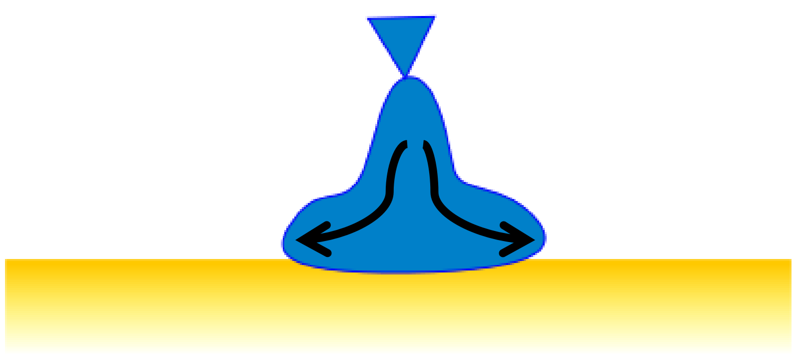
Motion and deformation

$$E_k = mgh - \Delta E$$

$$E_p = 0$$

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

Water flows to the sides



Motion and deformation

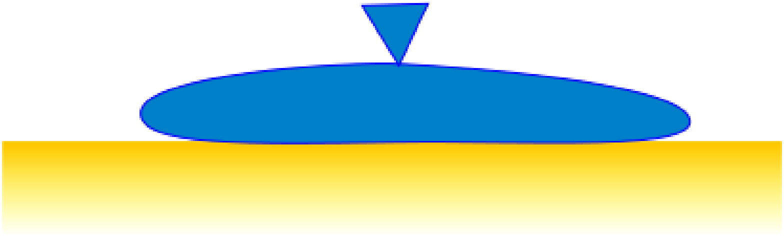
$$E_k = 0$$

$$E_p = 0$$

$$E_e \approx A + mgh$$

Maximal radius of balloon
Water stopped by rubber

Some energy lost
- water flows



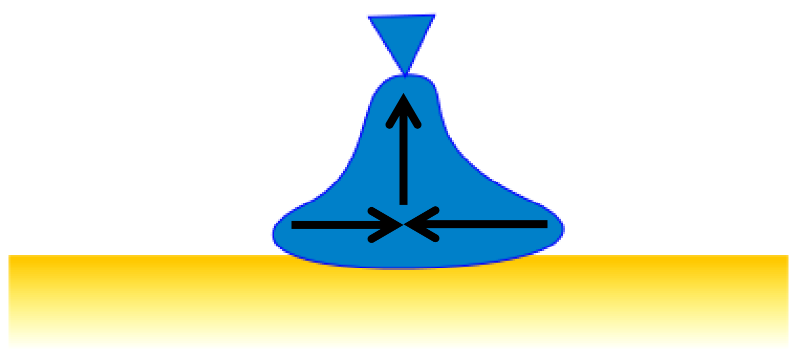
Motion and deformation

$$E_k = \Delta E$$

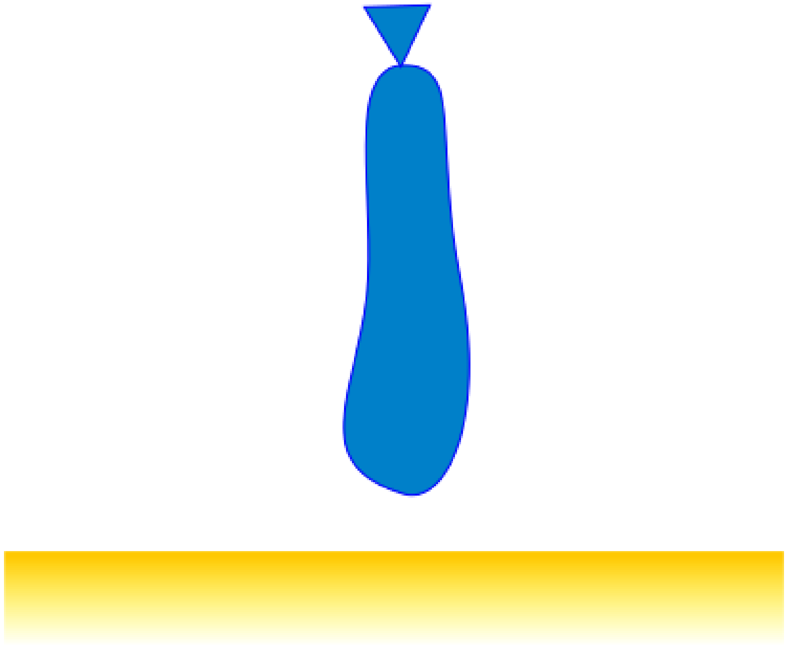
$$E_p = 0$$

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

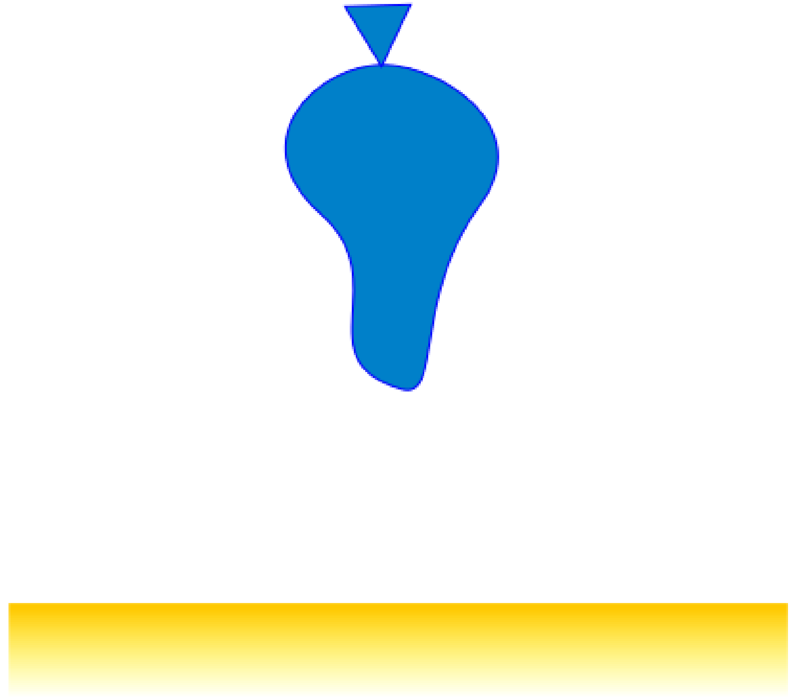
Rubber is contracting



Motion and deformation



Motion and deformation

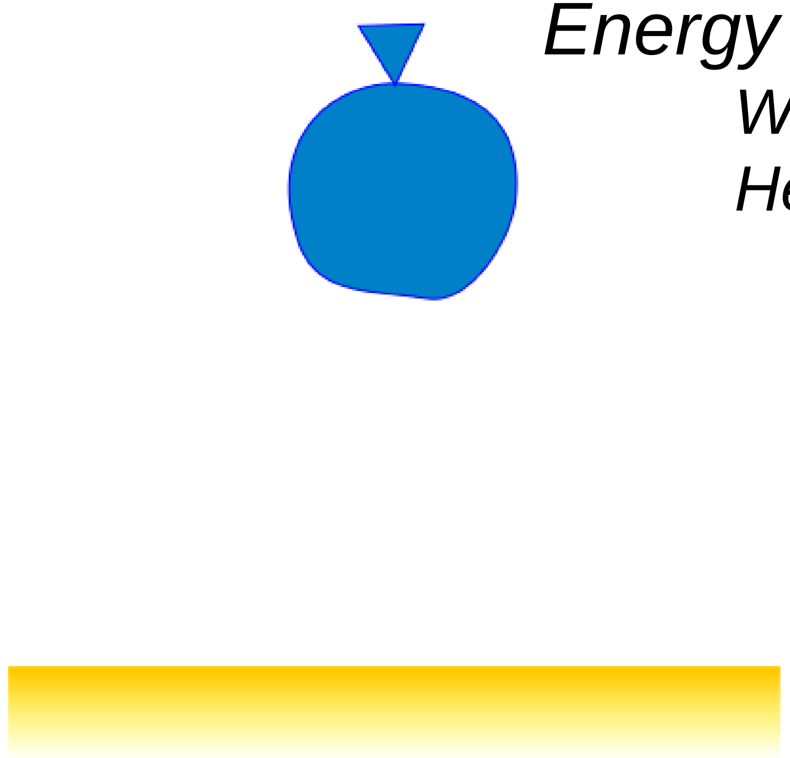


Motion and deformation

$$E_k = 0$$

$$E_p < mgh$$

$$E_e = A$$



Energy losses

Water convection

Heat

Different type of deformation

The view is from the bottom of the aquarium

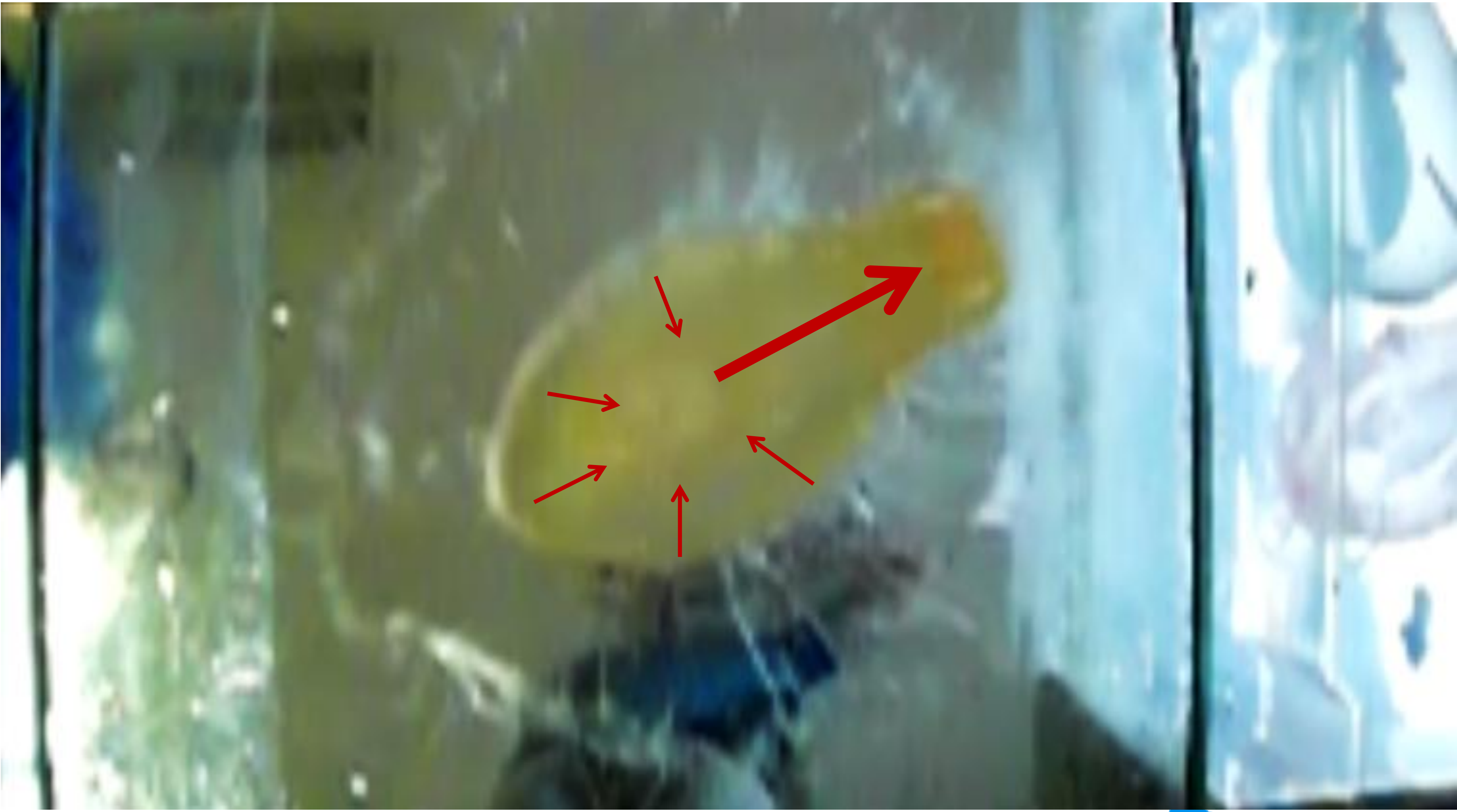
Different type of deformation

Elongated balloo

Easier to stretc

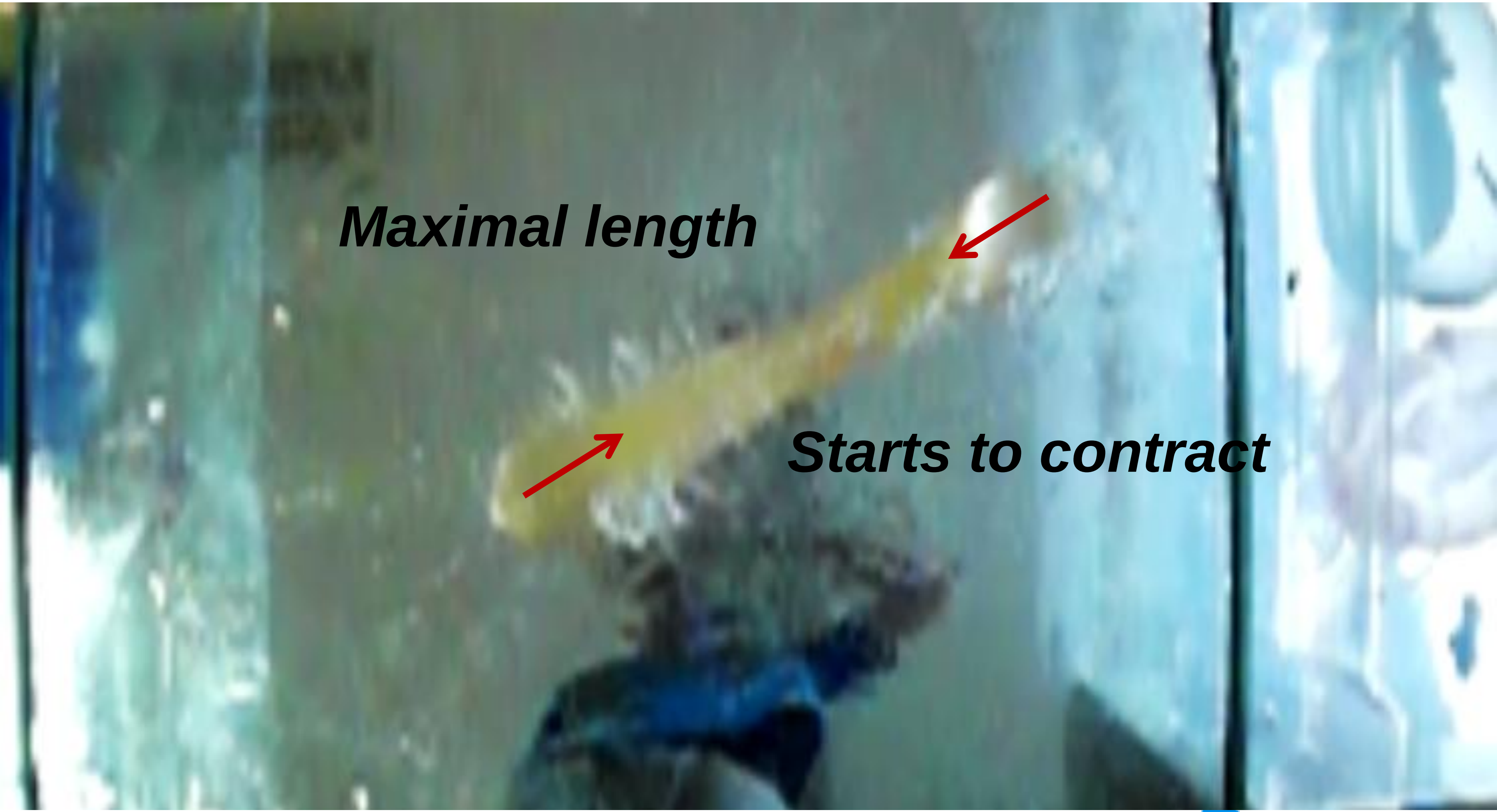
Different type of deformation

Different type of deformation



Different type of deformation

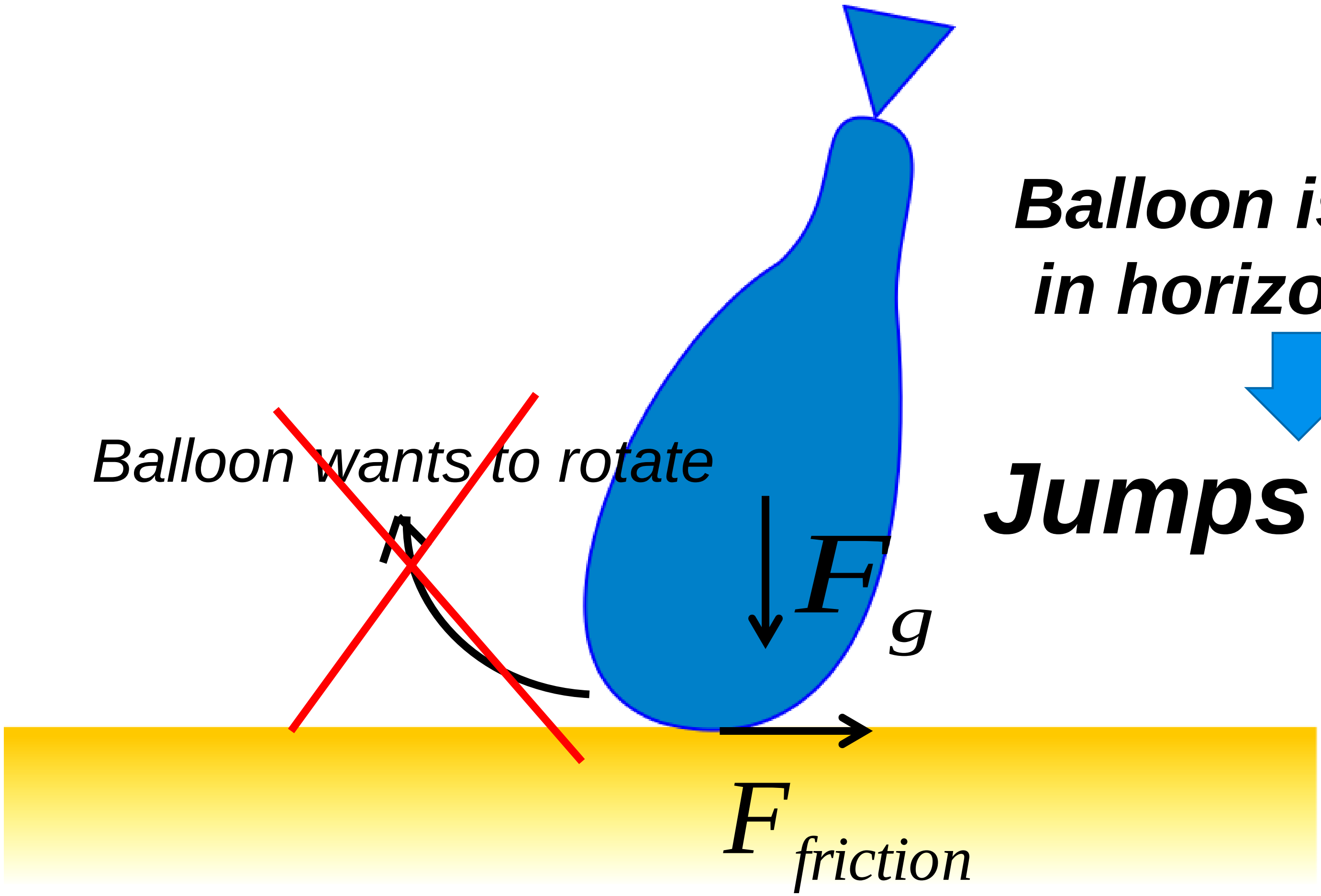
Different type of deformation



Different type of deformation

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

Rebound



Balloon is acceleratin
in horizontal way

Jumps to the si

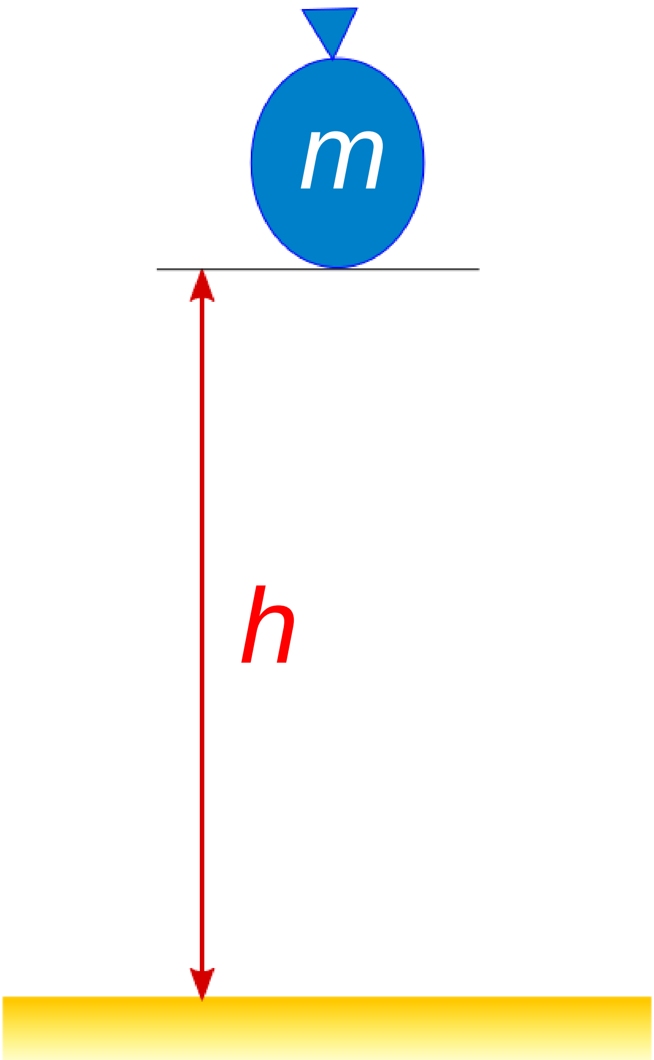
Jumping balloon

Jumping balloon

Jumping balloon

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

Apparatus



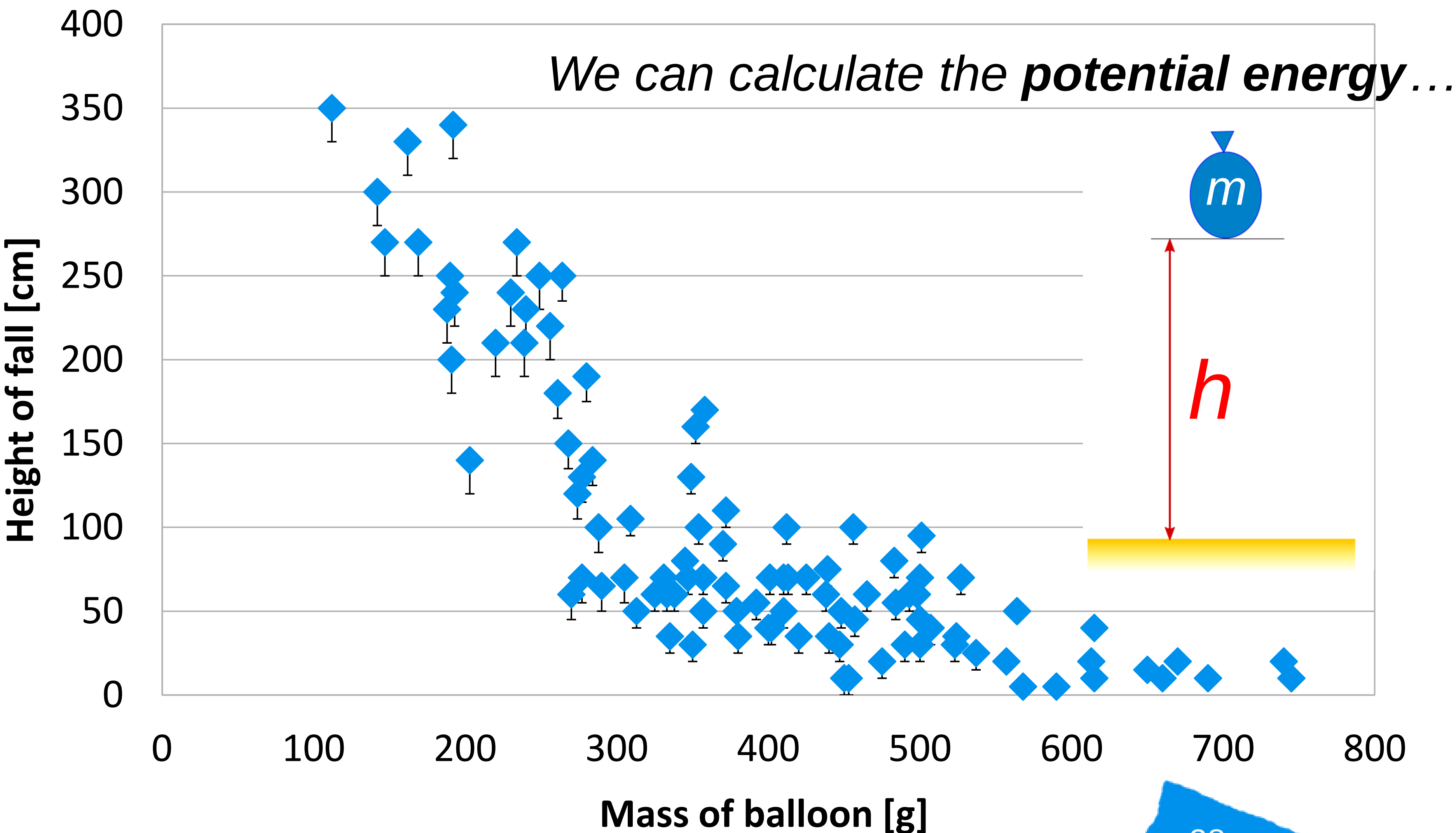
Balloon with mass **m**

Changing height **h** from **h=0cm**

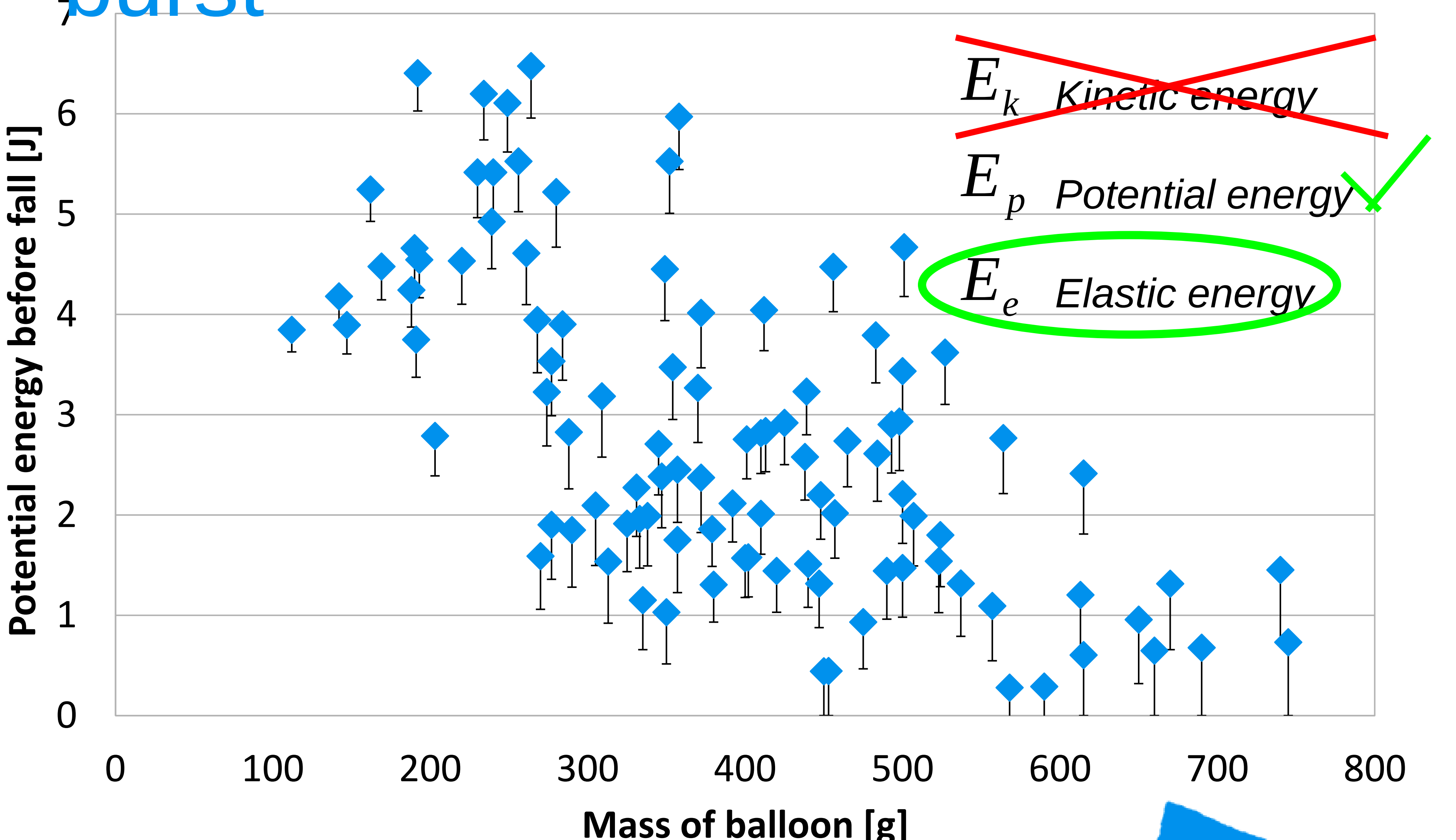
Find the **smallest h,** when it bursts

Do it with ***<u>many</u>*** balloons

Height, which causes burst

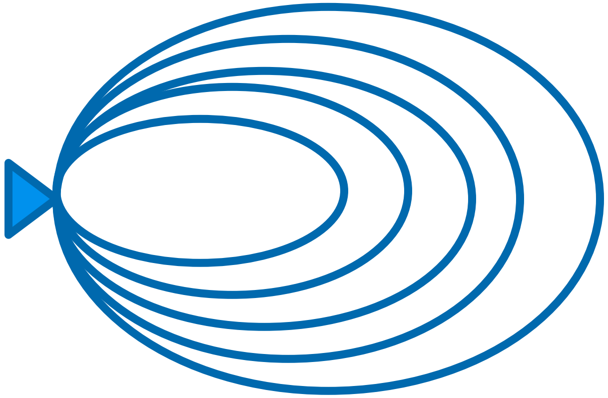


Potential energy needed to burst



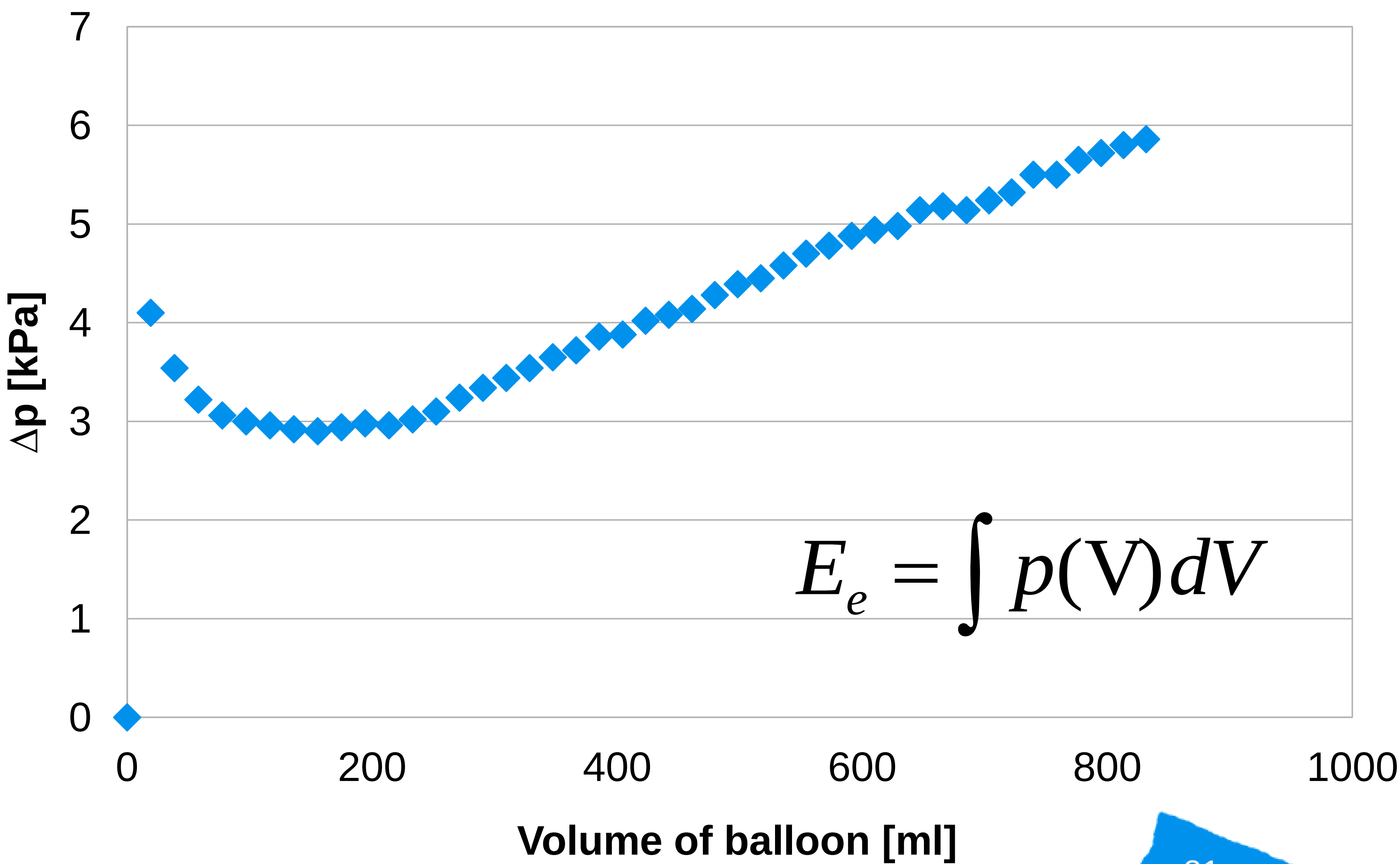
Elastic energy of balloon

Can be calculated from
pressure change during inflation

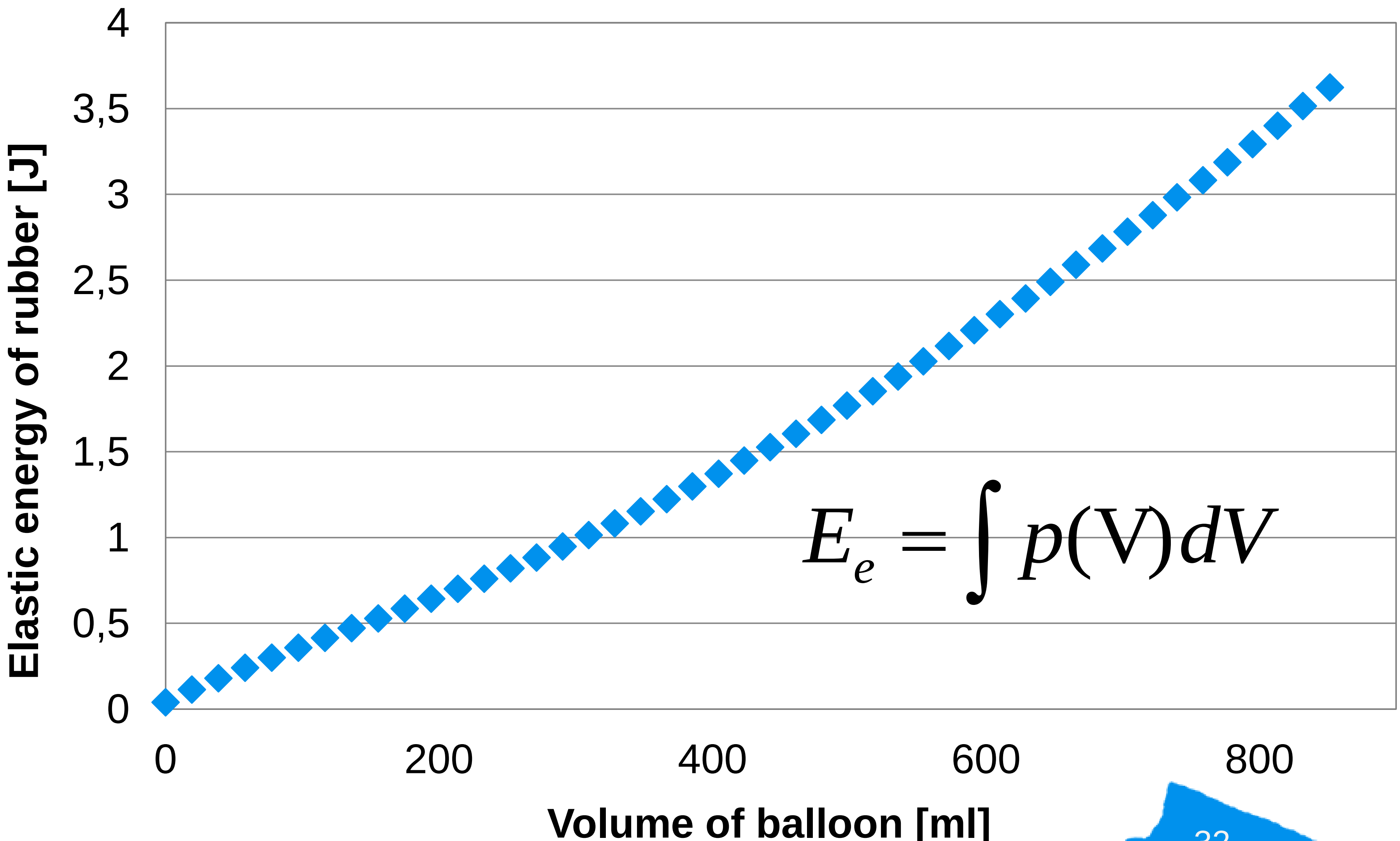


$$E_e = \int p(\mathrm{V})dV$$

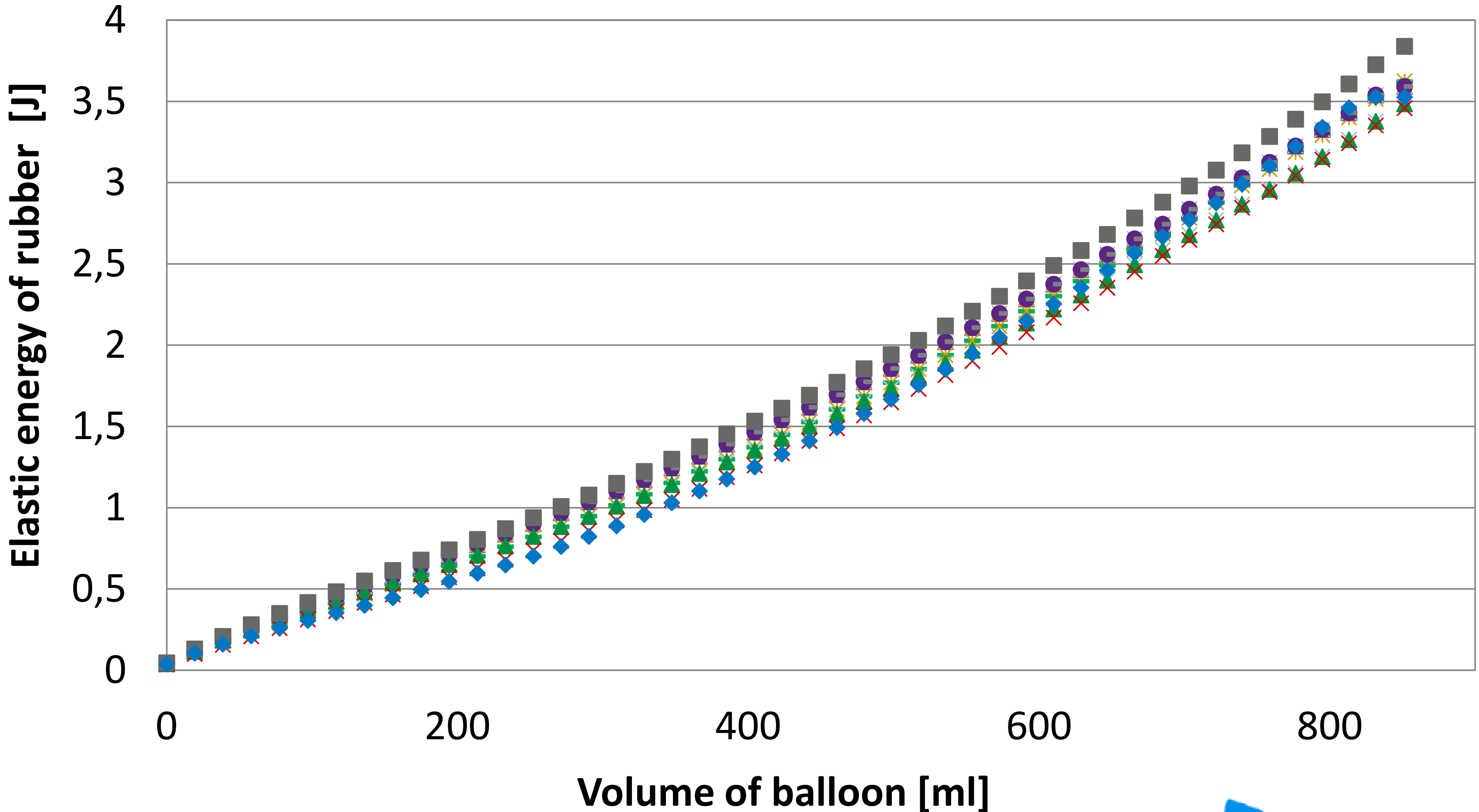
Pressure measurement



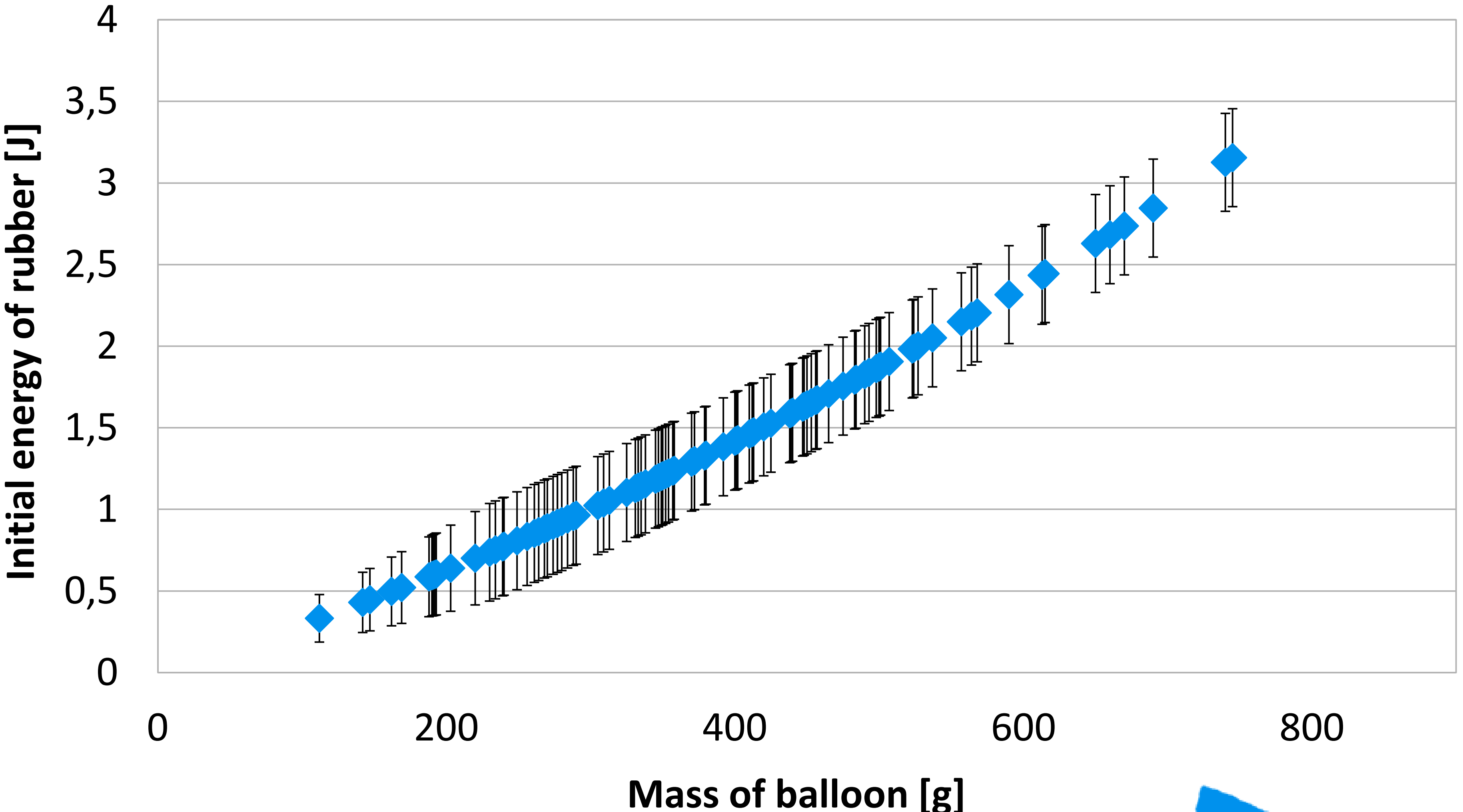
Elastic energy of balloon



More measurements of elastic energy

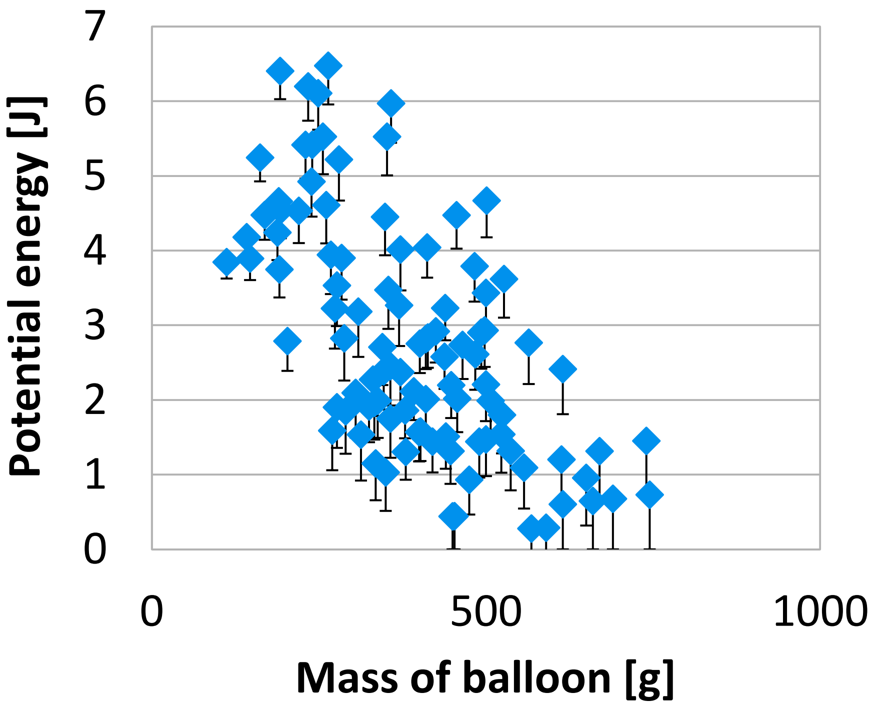


Elastic energy of balloon with water

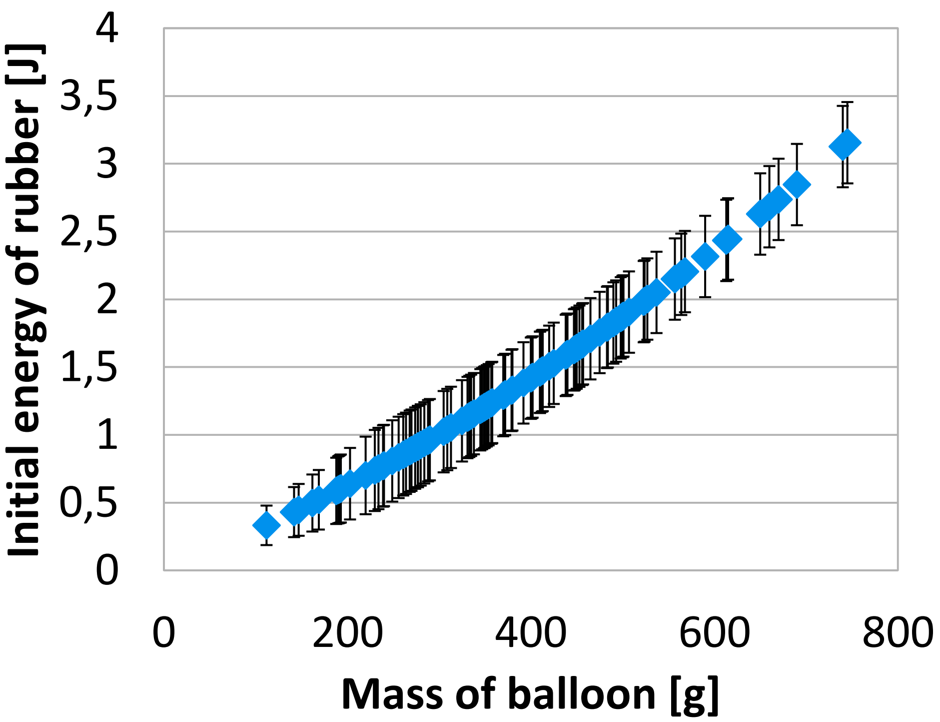


Total energy given to balloon

Potential energy of fall



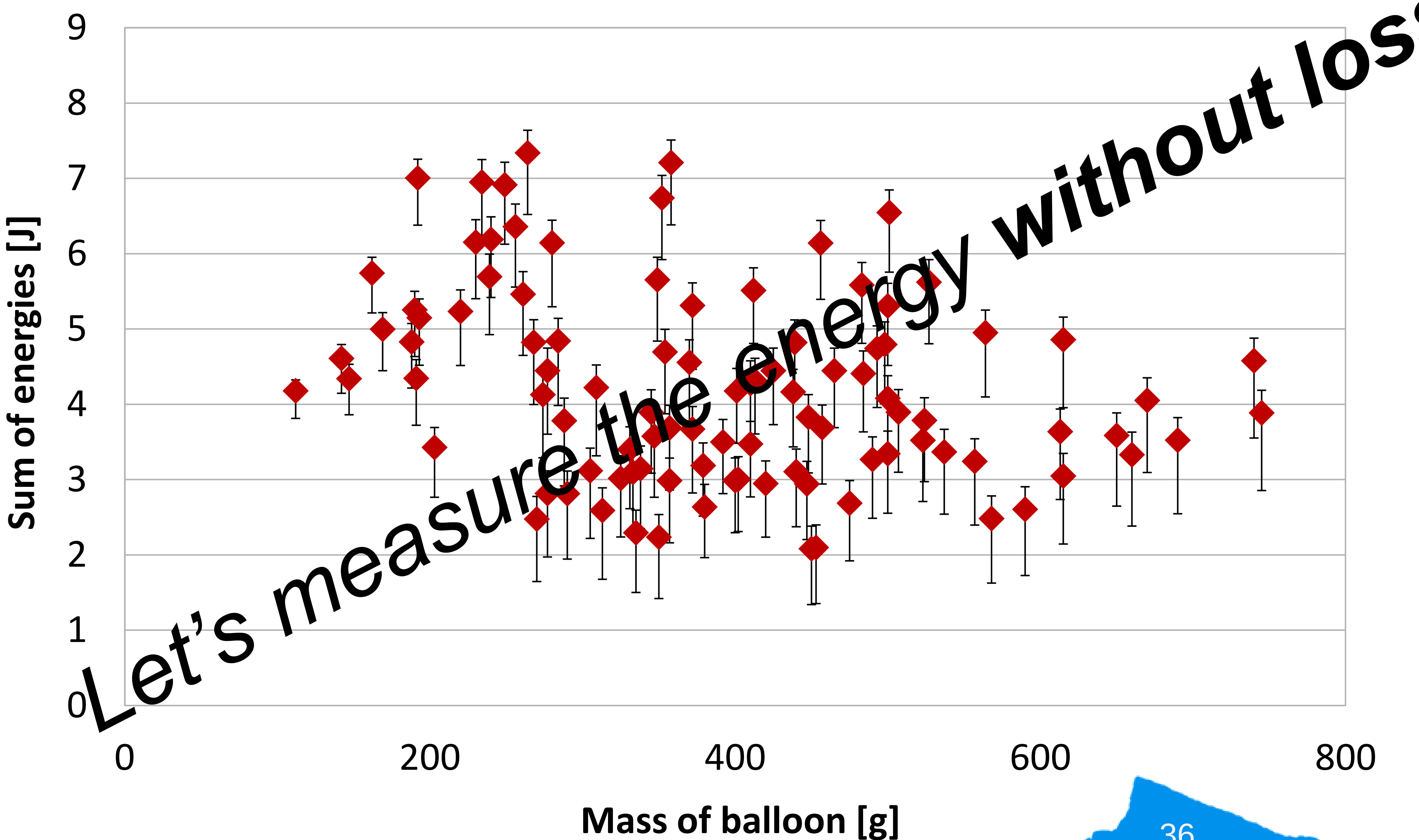
Elastic energy



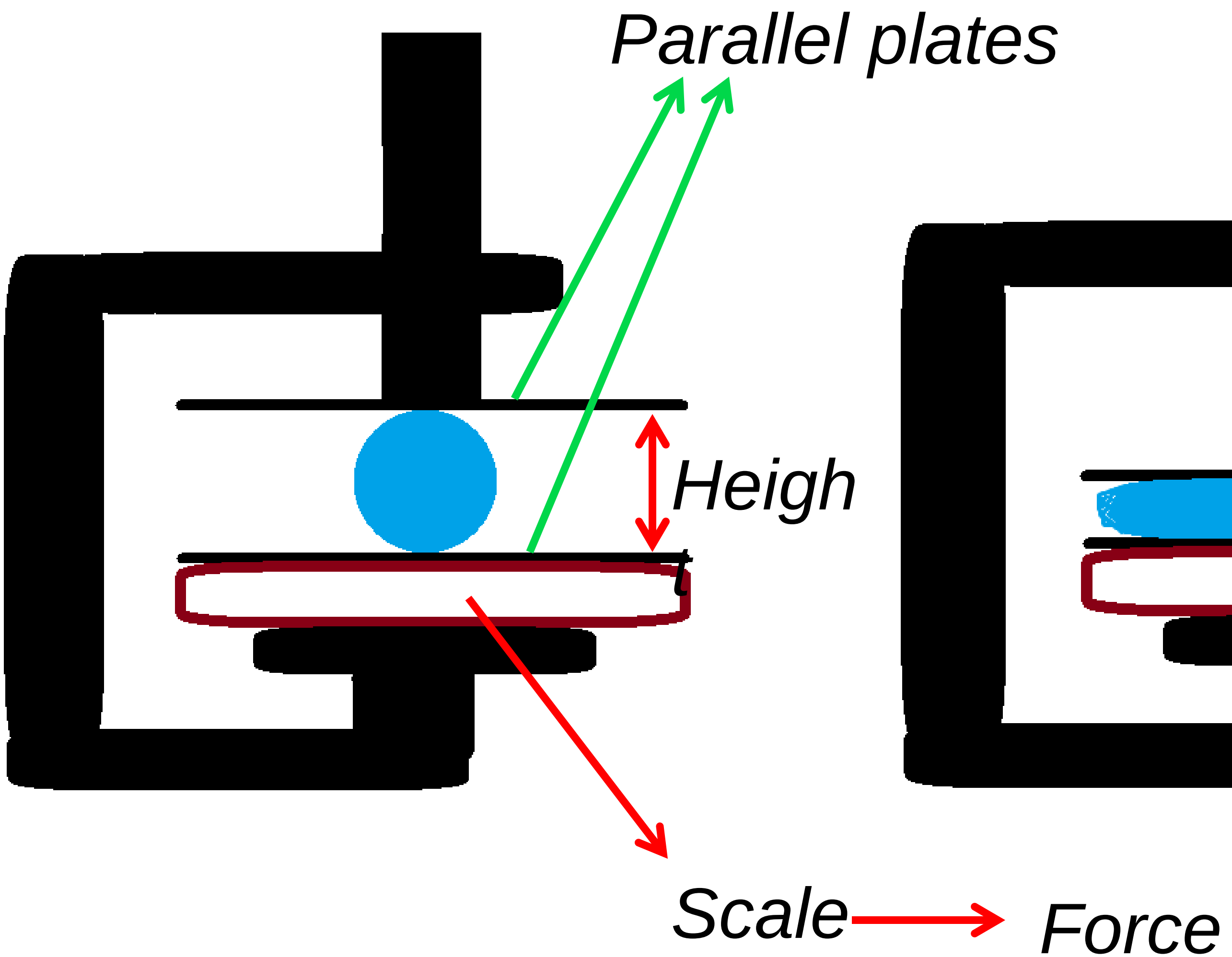
$$E_{total} = E_p + E_e$$

Total energy needed to **burst**

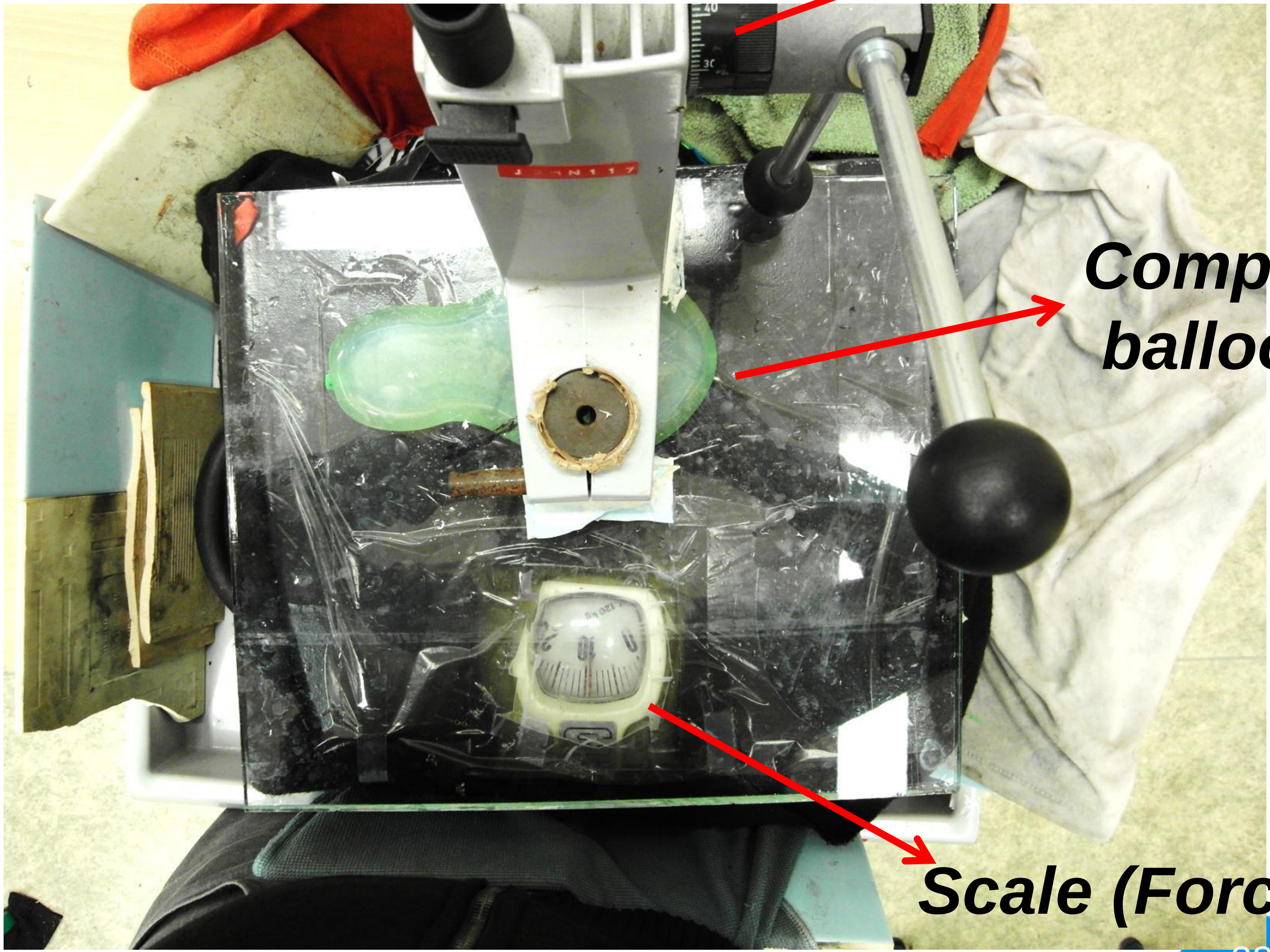
(Potential + Elastic)



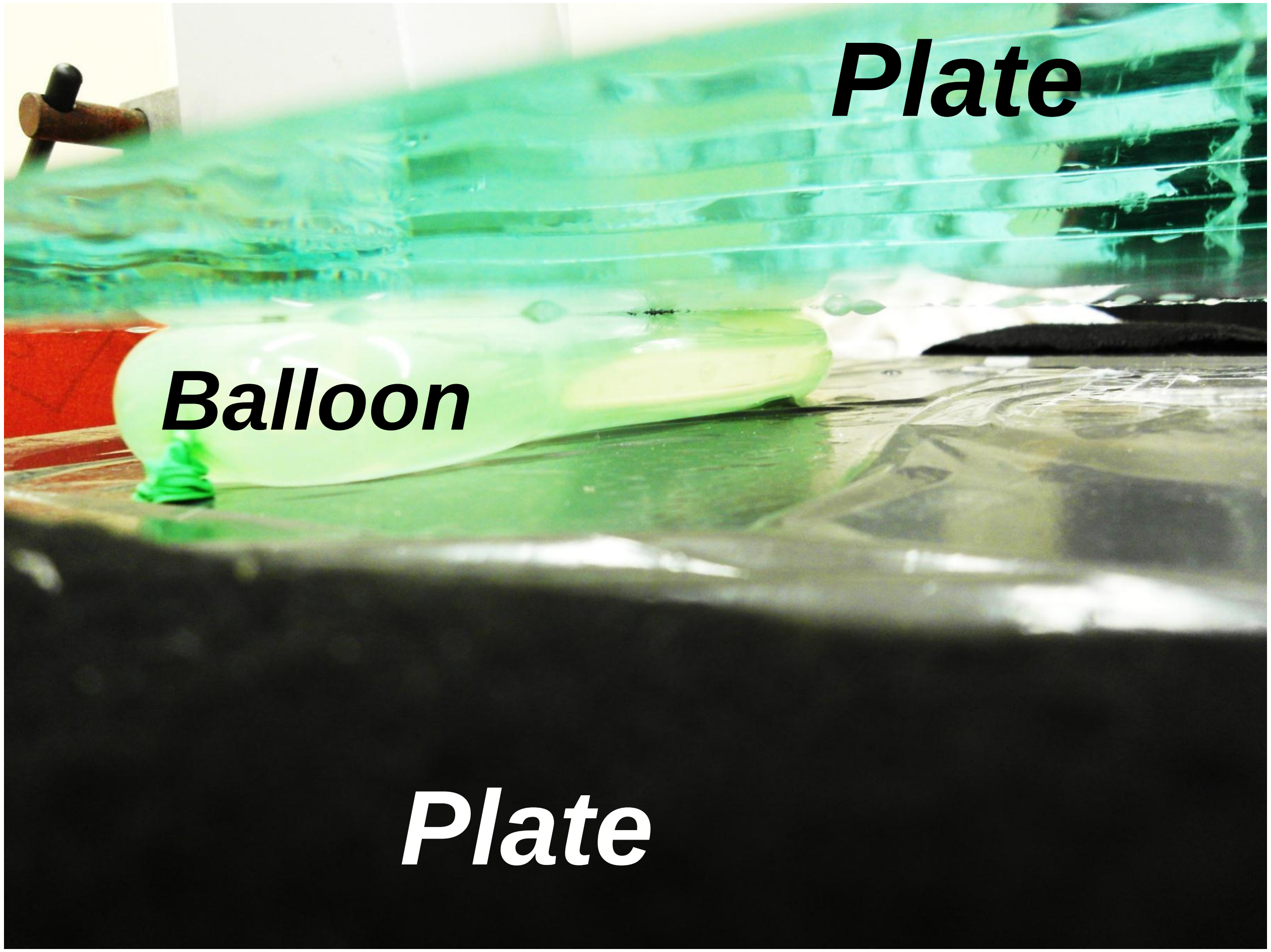
Compressing



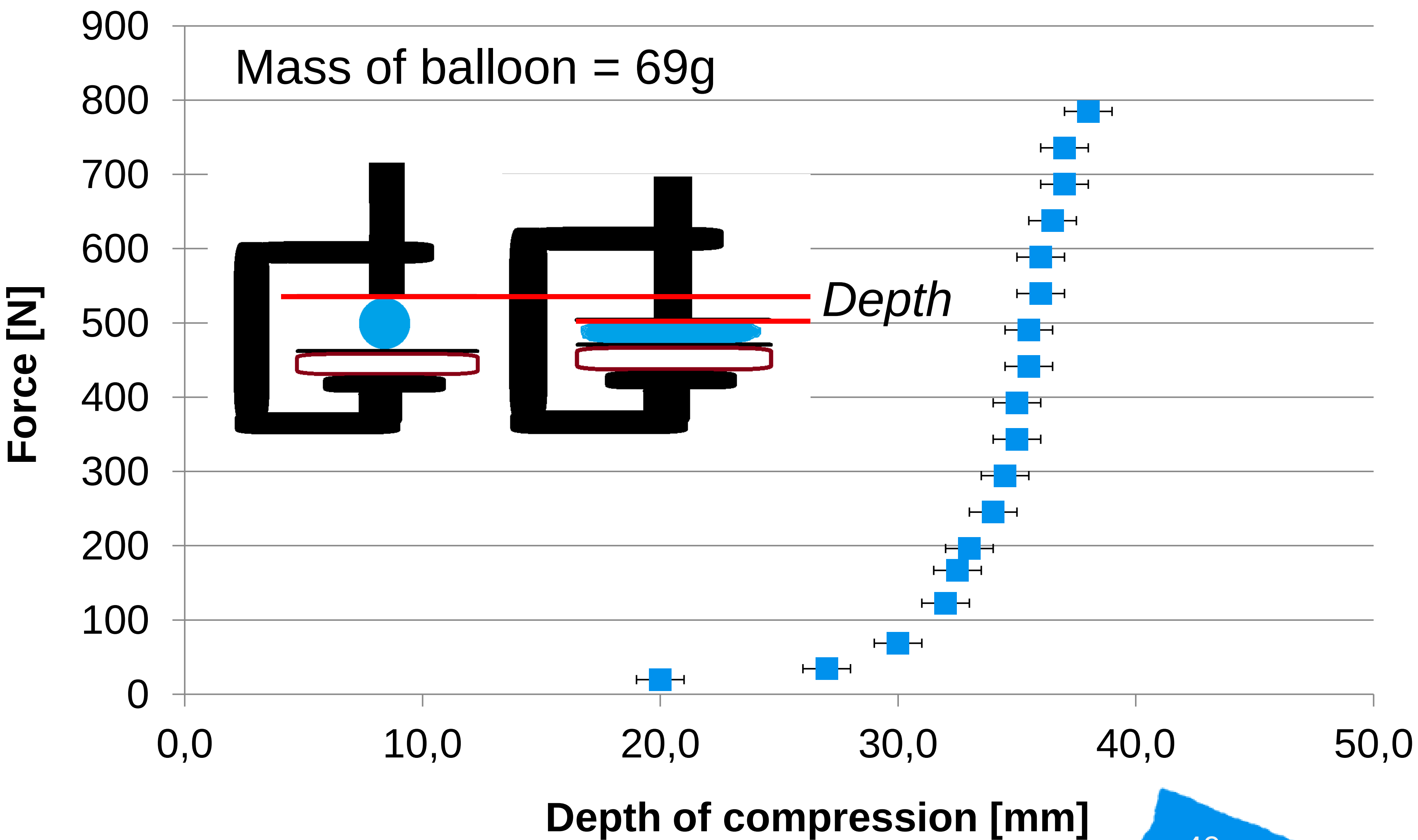
Apparatus



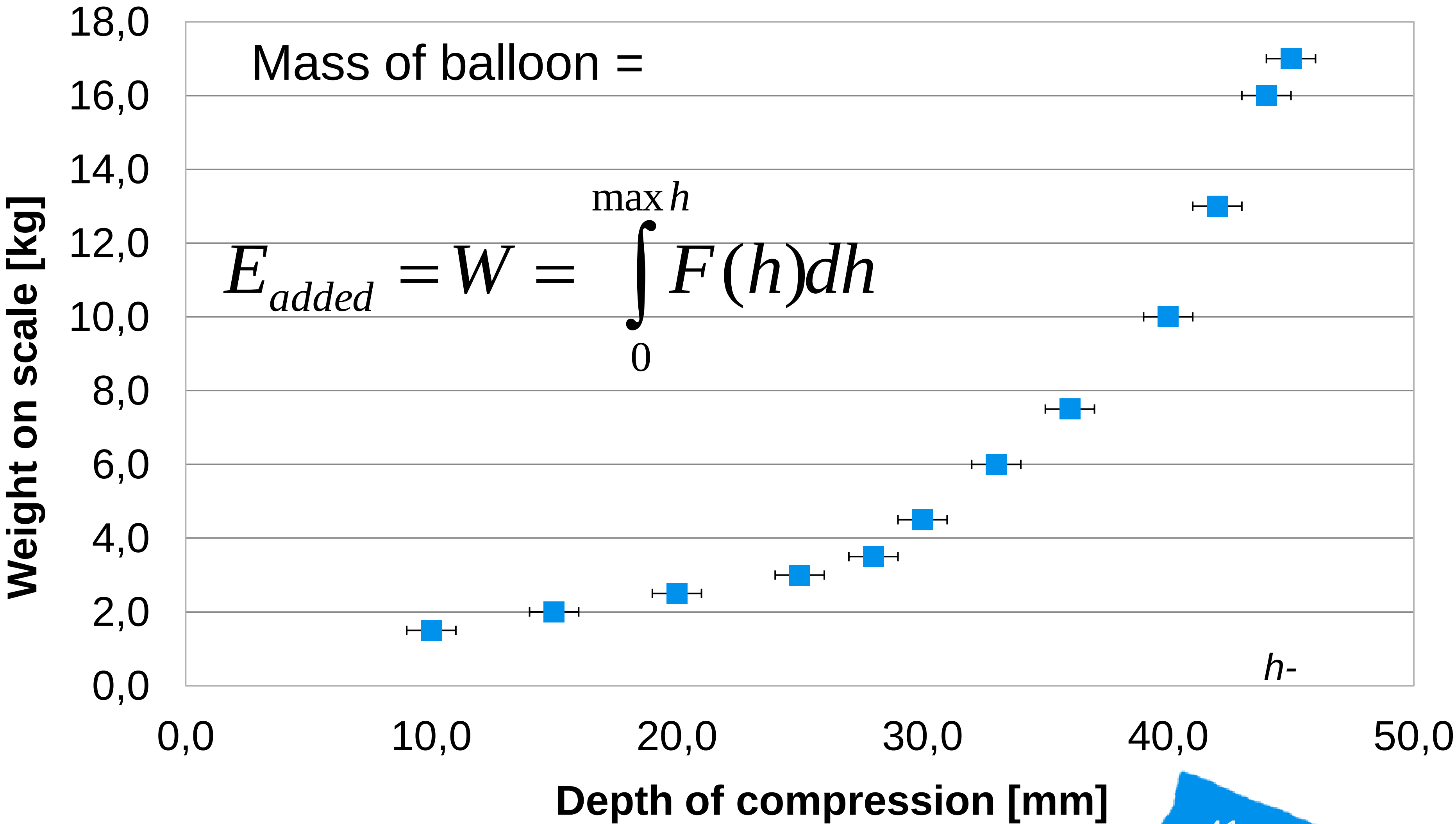
Compressed balloon



Force vs. depth of compression



Force vs. depth of compression

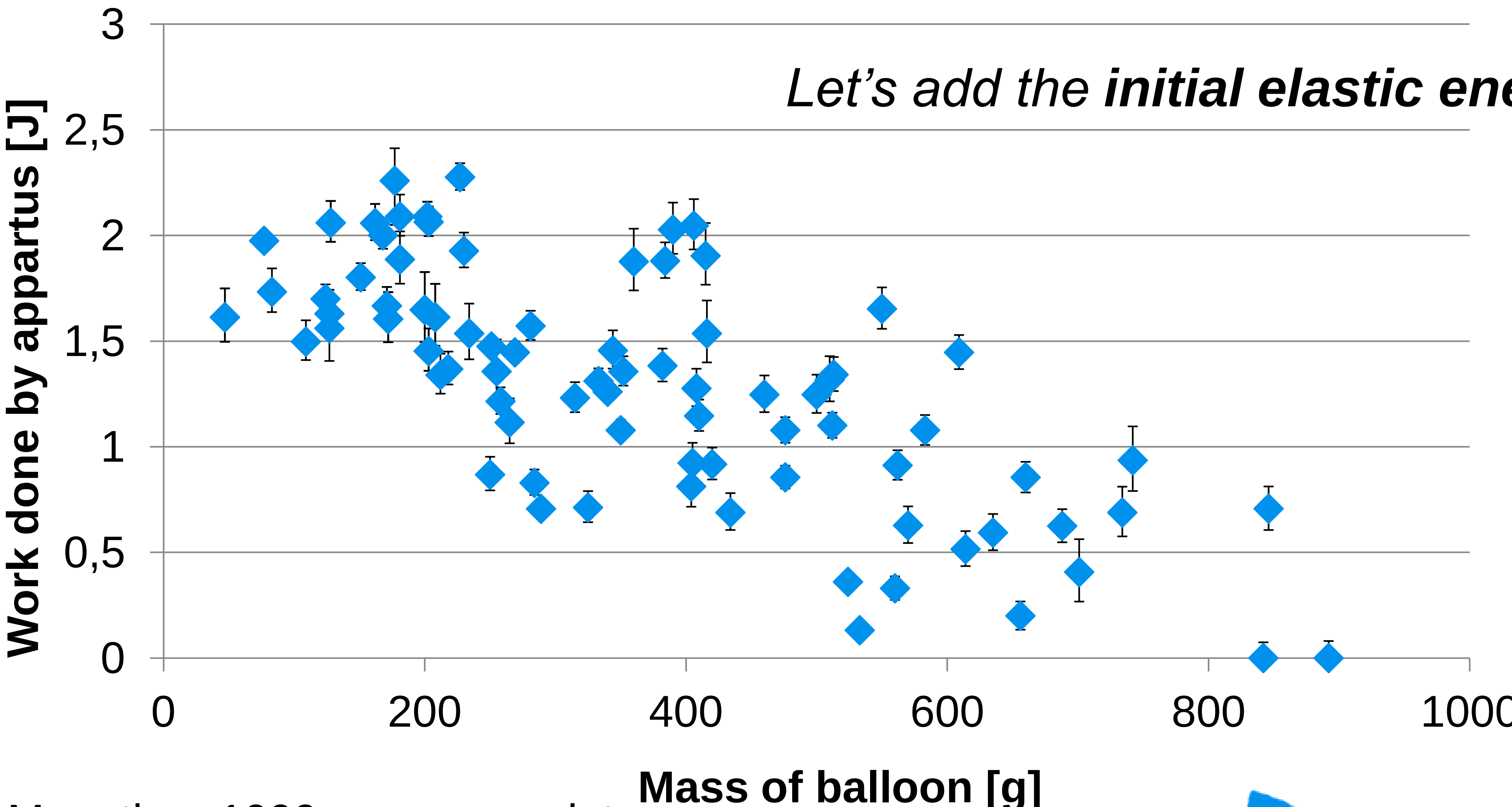


$$E_{added} = W = \int_{0}^{\max h} F(h)\,dh$$

Work done by apparatus

for many balloon volumes

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

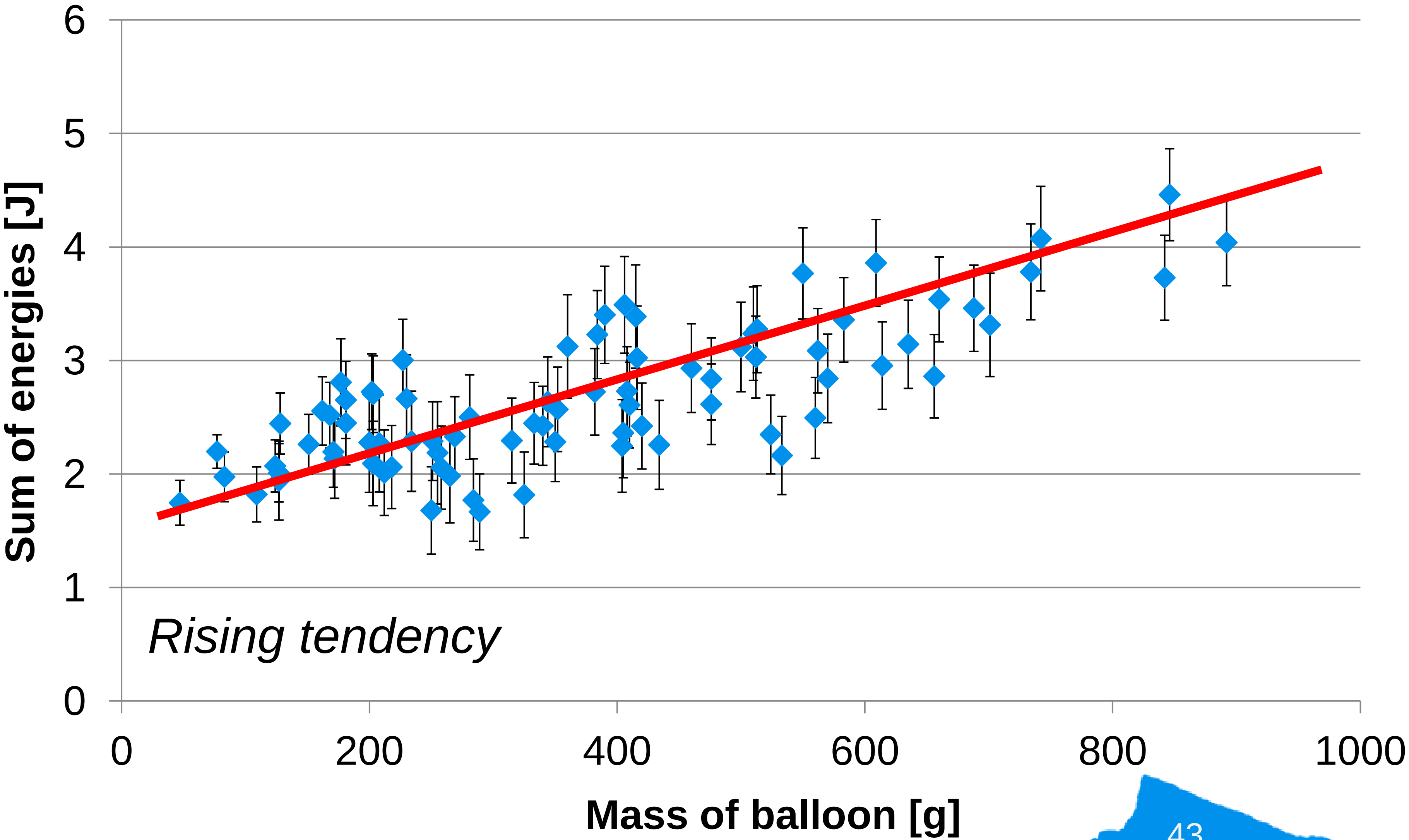


*Let's add the **initial elastic energ***

More than 1000 measure-points

Total energy needed for **burst**

(Work + Elastic)



Big balloon

Almost maximal tension

Almost maximal tension

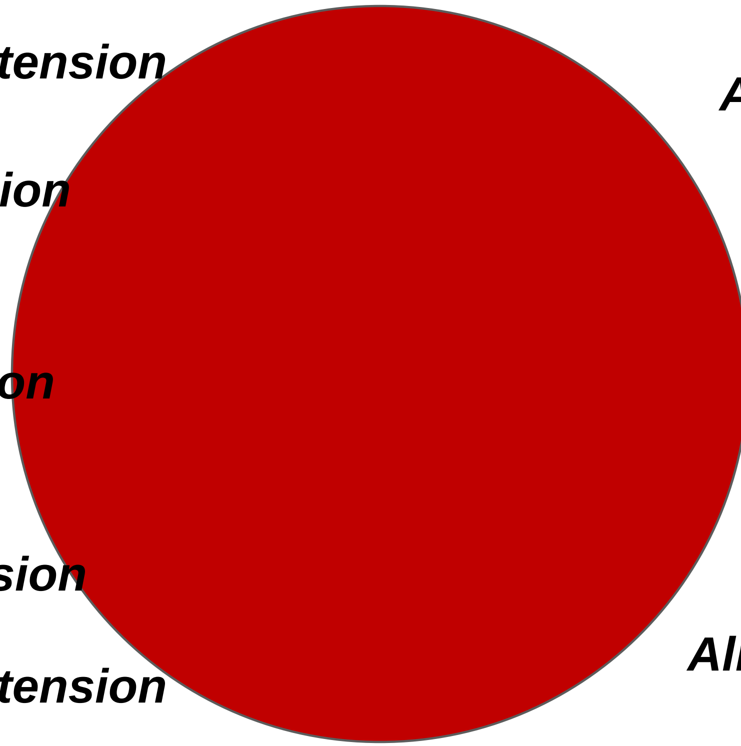
Almost maximal tension

Almost maximal tension

Almost maximal tension

Almost maximal tension

Almost maximal tension



Almost maximal tension

Almost maximal tension

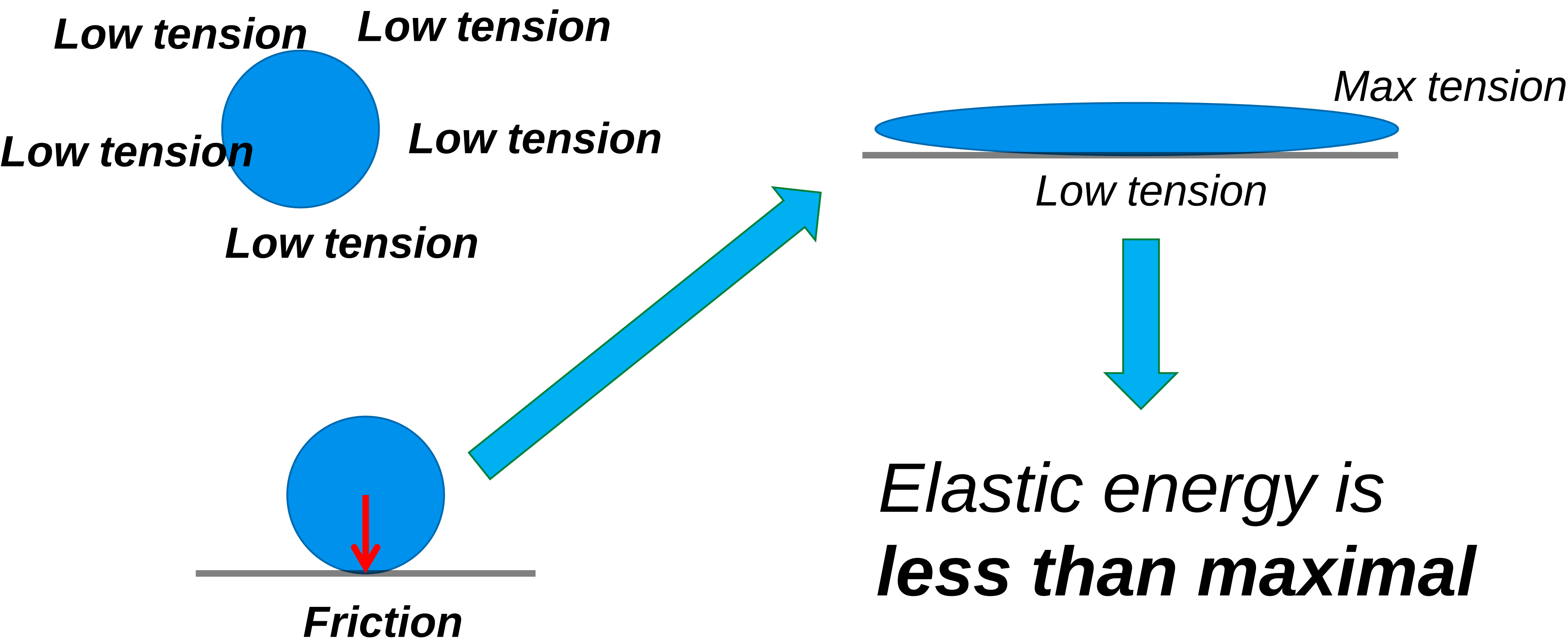
Almost maximal tension

Almost maximal tension

Almost maximal tension

Elastic energy is almost maxima

Small balloon

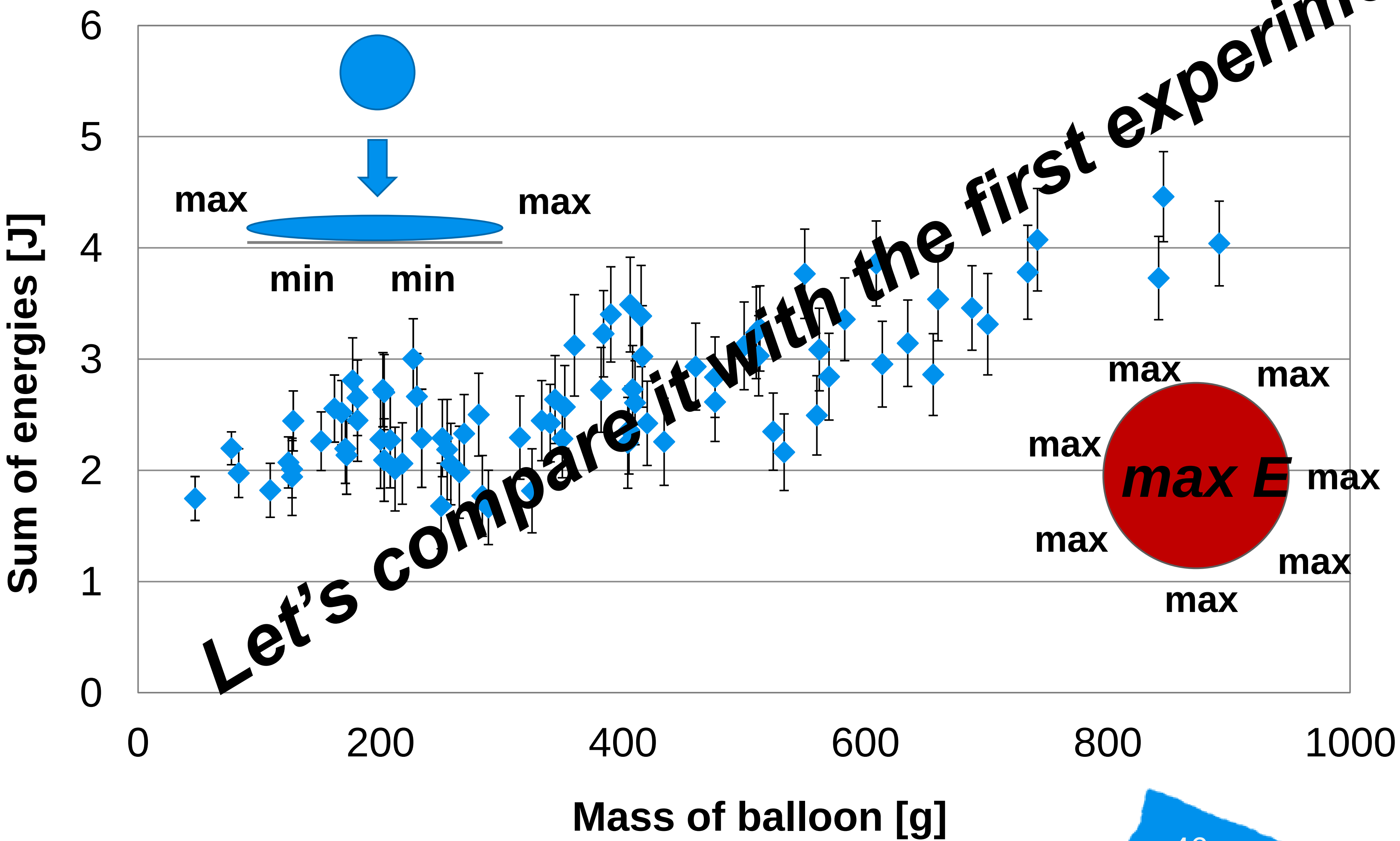


Elastic energy is ***less than maximal***

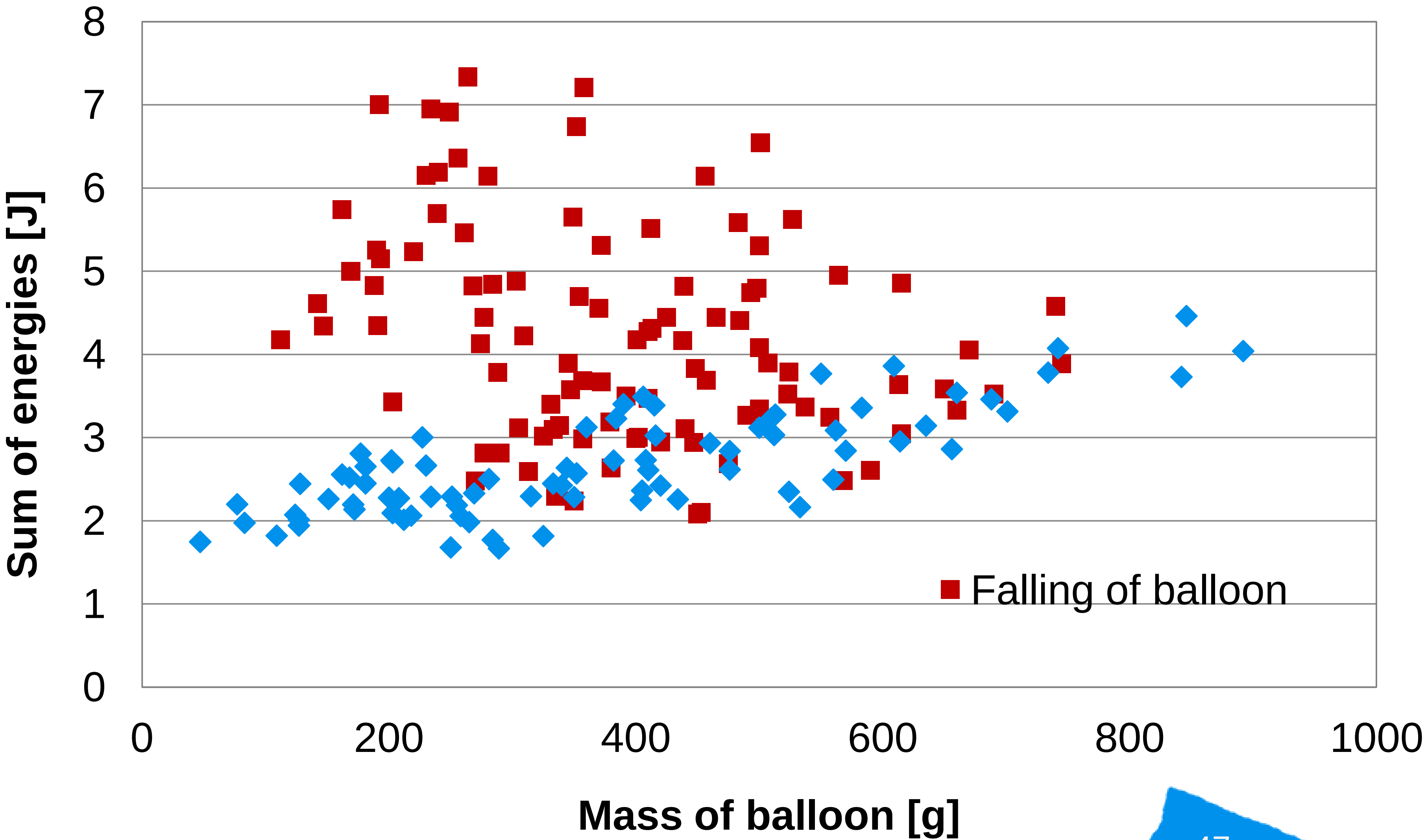
Tension at the bottom remains the same

Total energy needed for **burst**

(Work + Elastic)



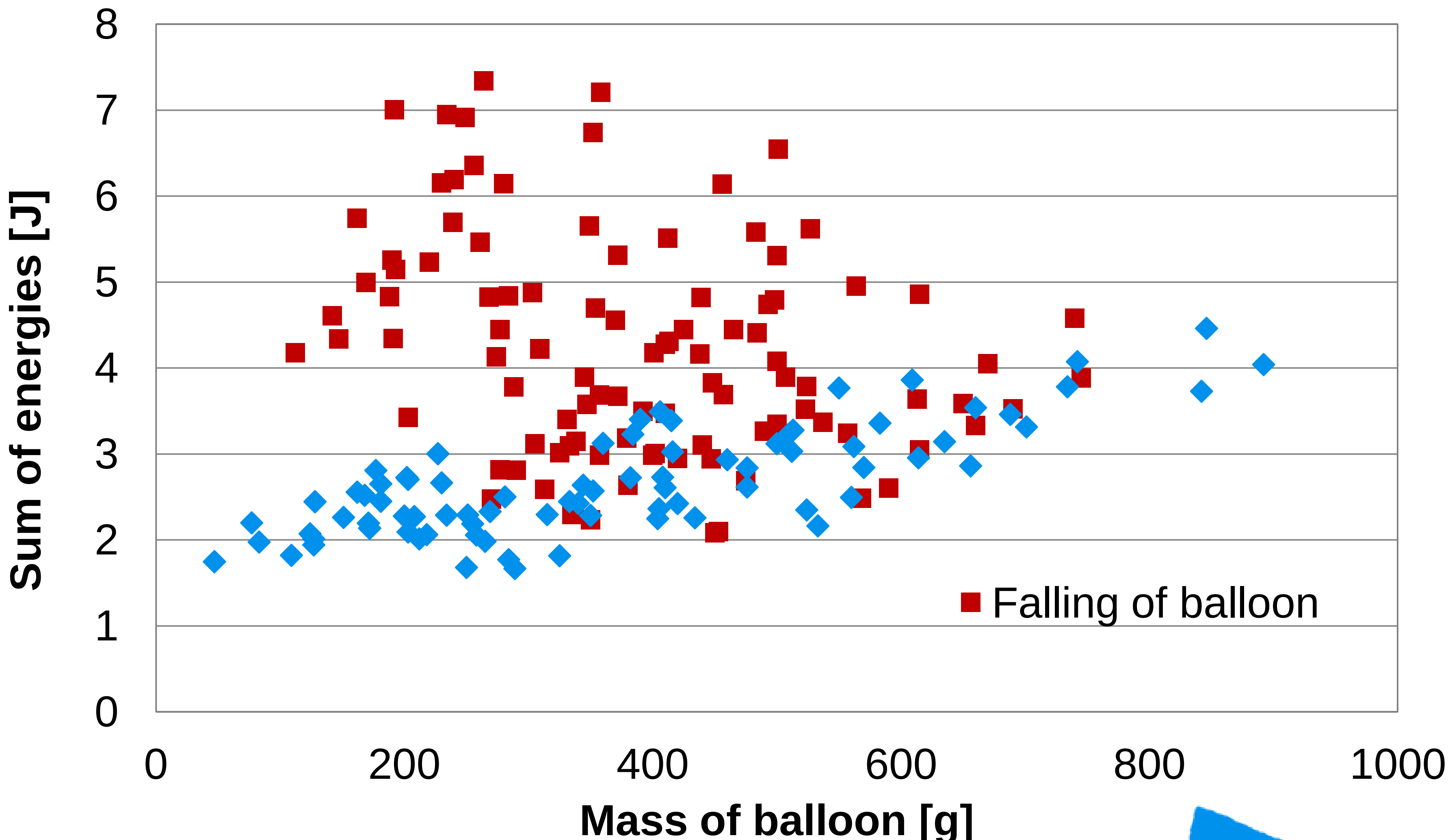
Energy needed to **burst** trough **fall** & through **compression**



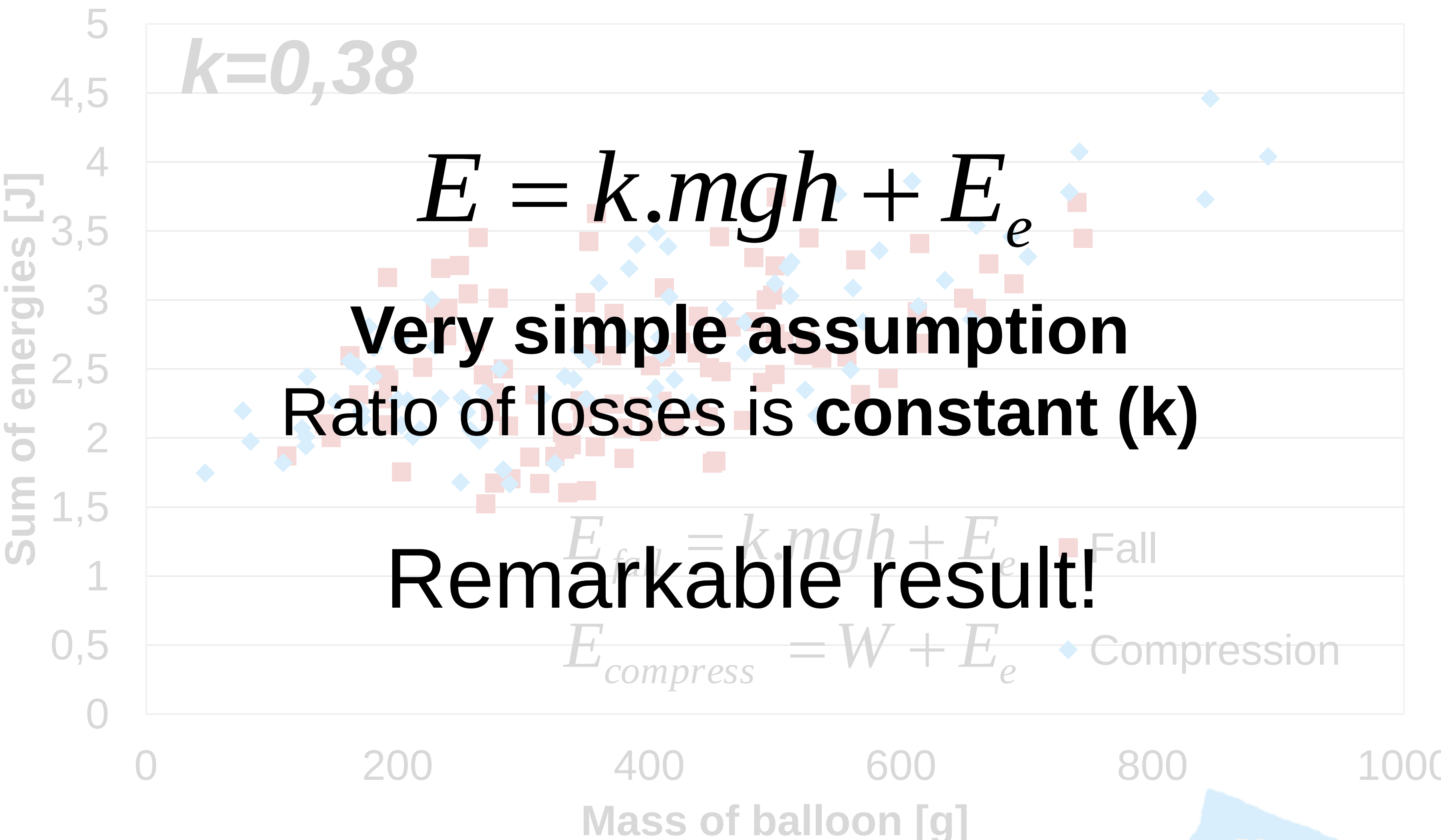
Falling balloon

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**



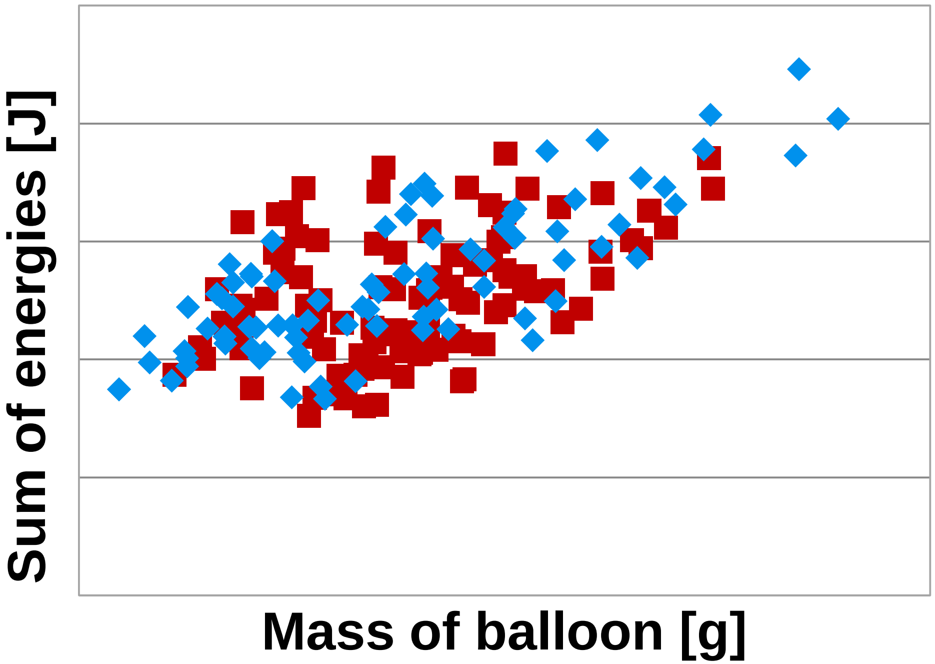
$$E = k.mgh + E_e$$

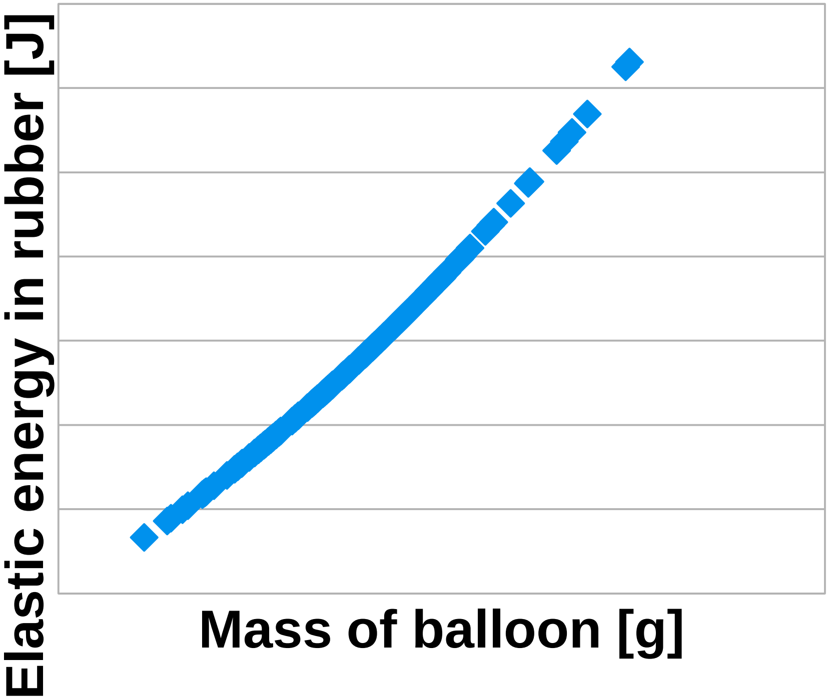
Very simple assumption

Ratio of losses is **constant (k)**

Remarkable result!

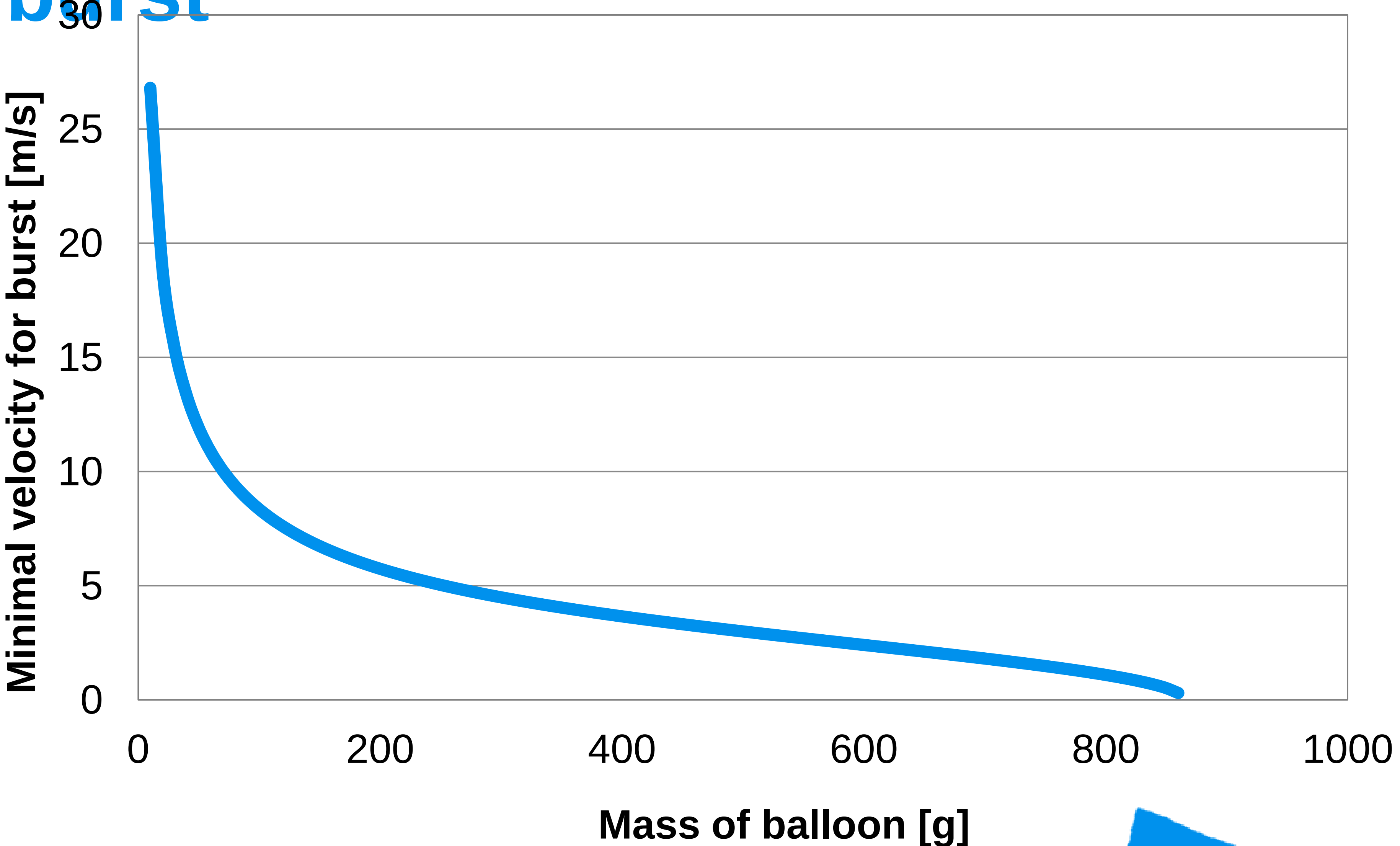
What we have





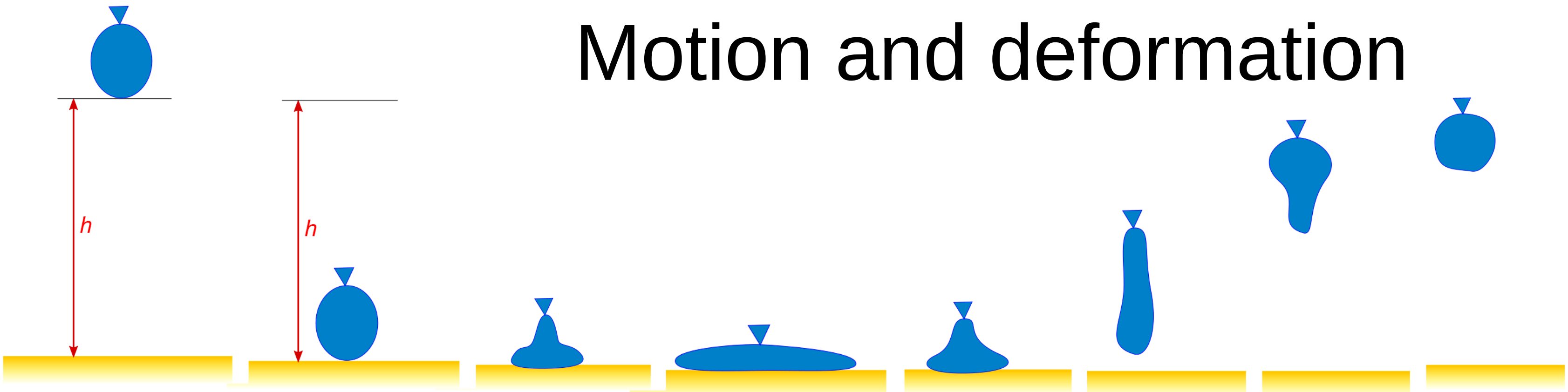
*We can derive approximately the **velocity** of throw needed to burst a balloon*

Approximate velocity needed for **burst**

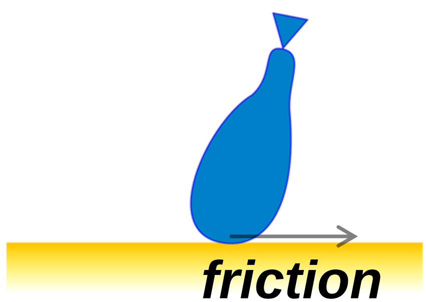


Summary

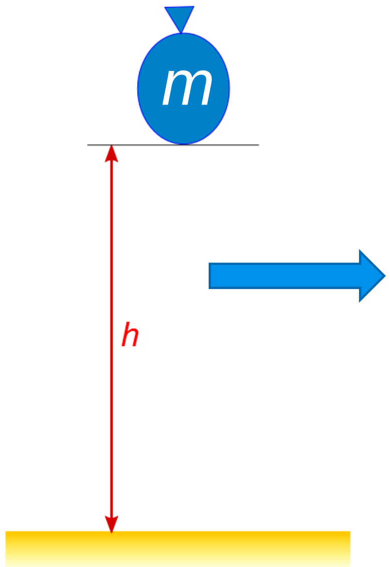
Motion and deformation

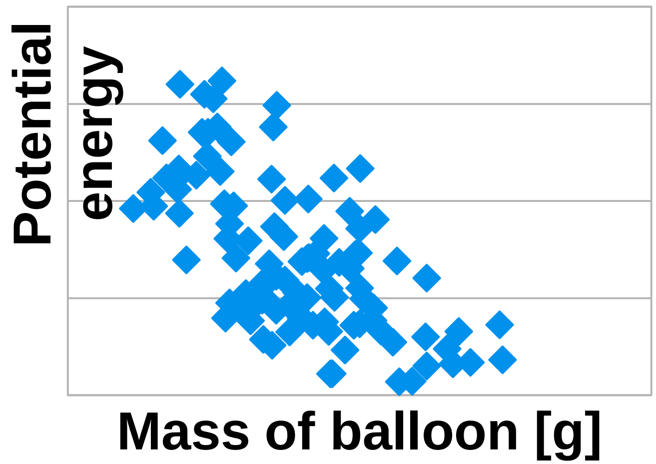


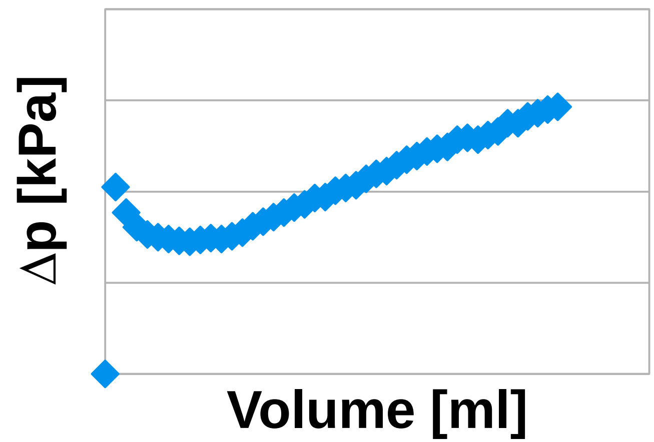
Rebound

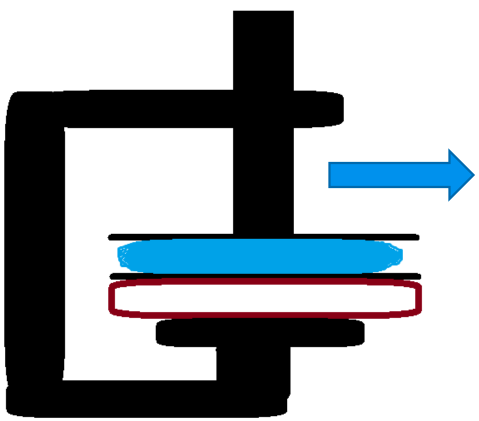


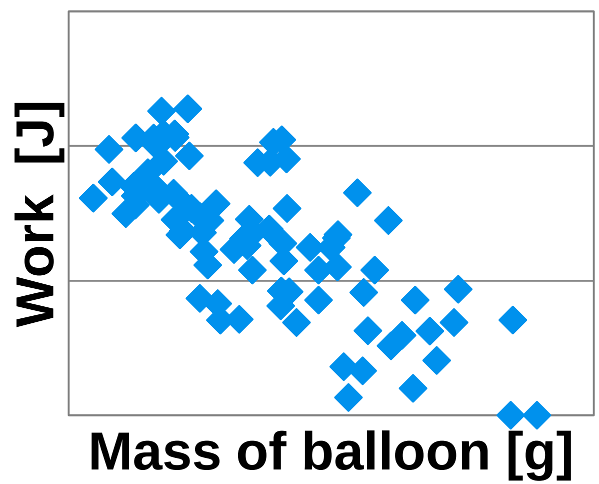
Summary - Burst

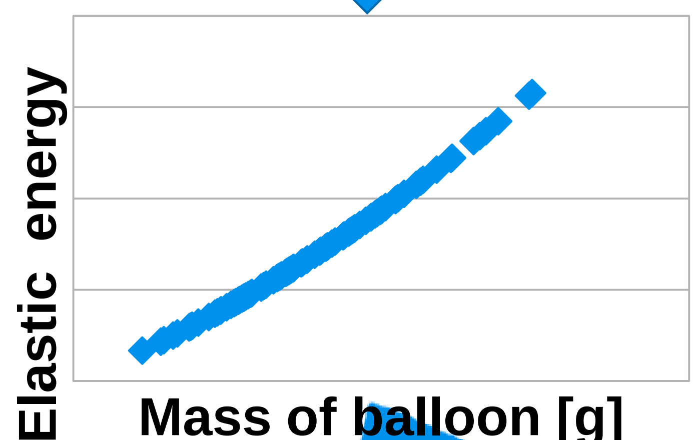




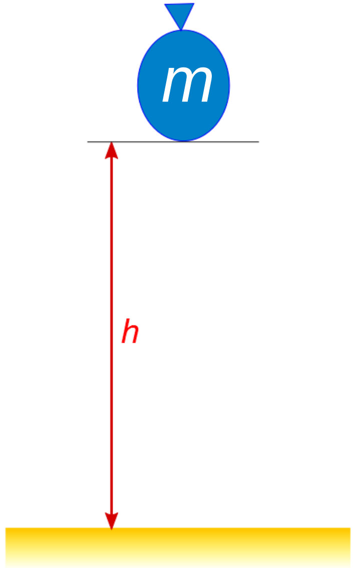


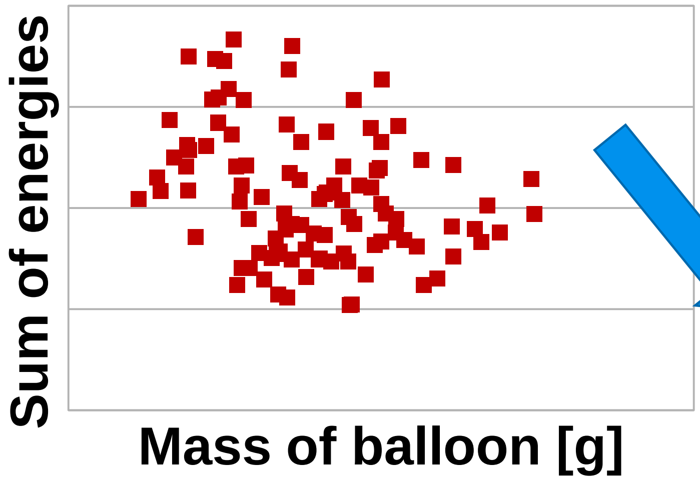




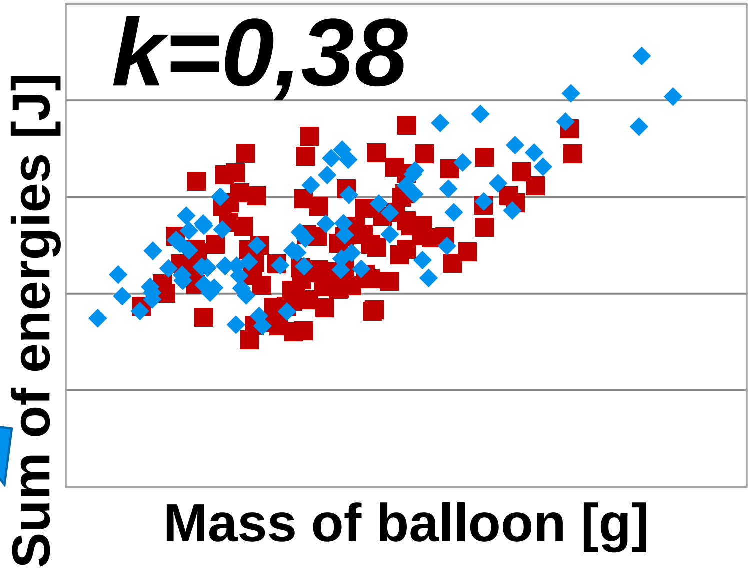


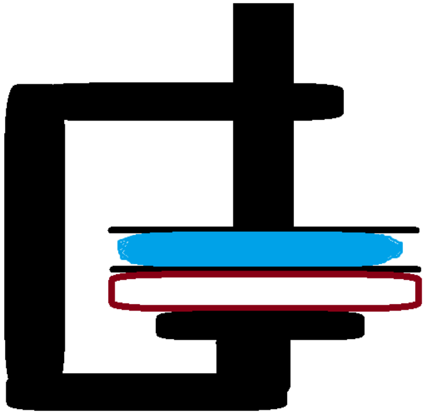
Summary - Burst

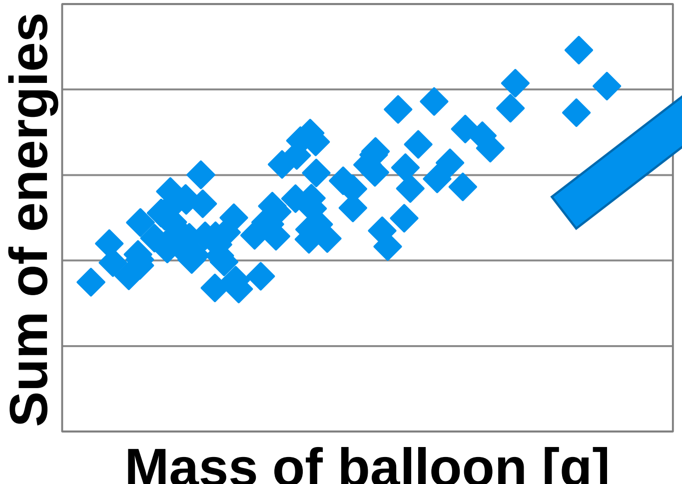




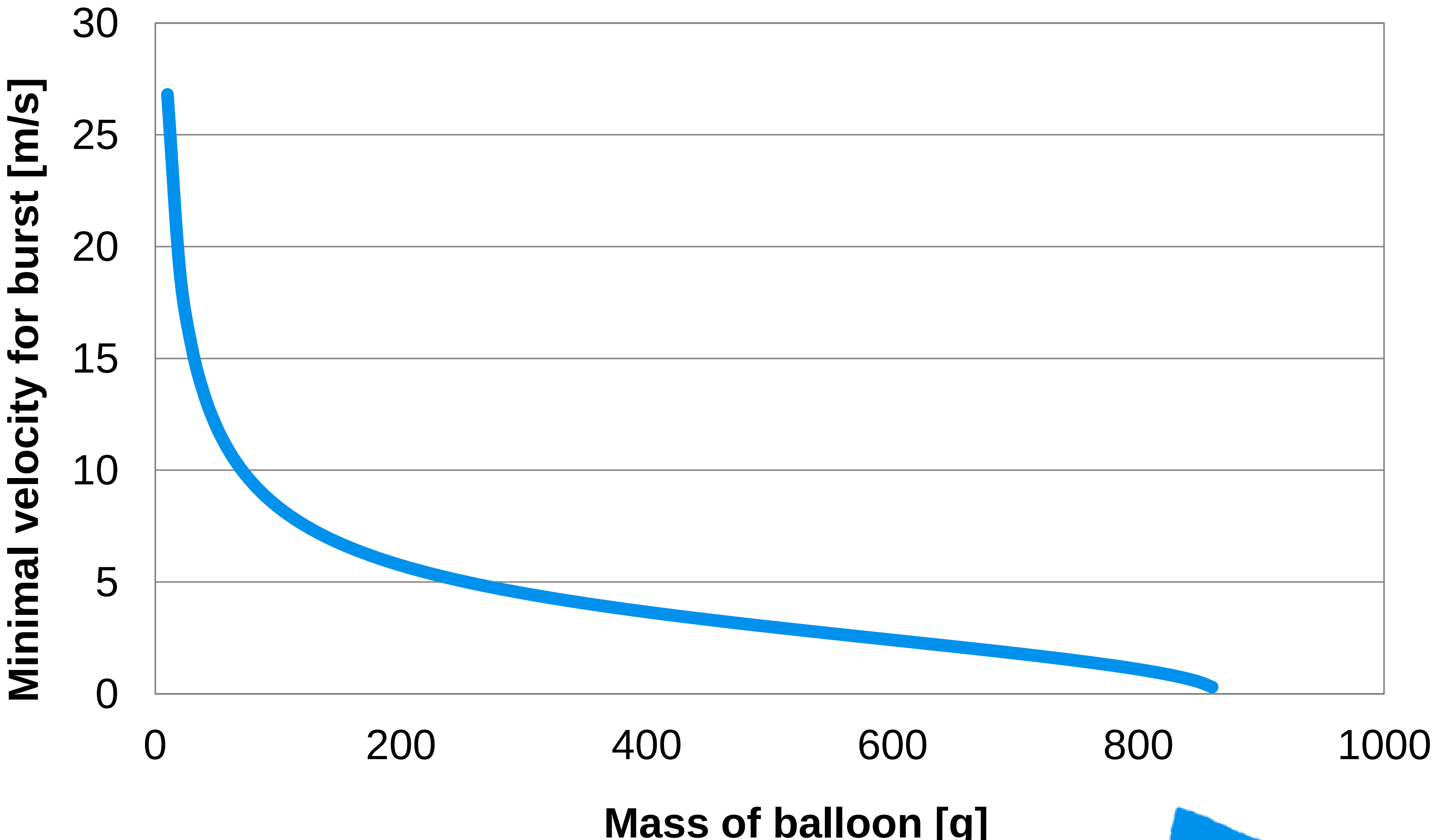
$$E_{total} = kE_p + E_e$$





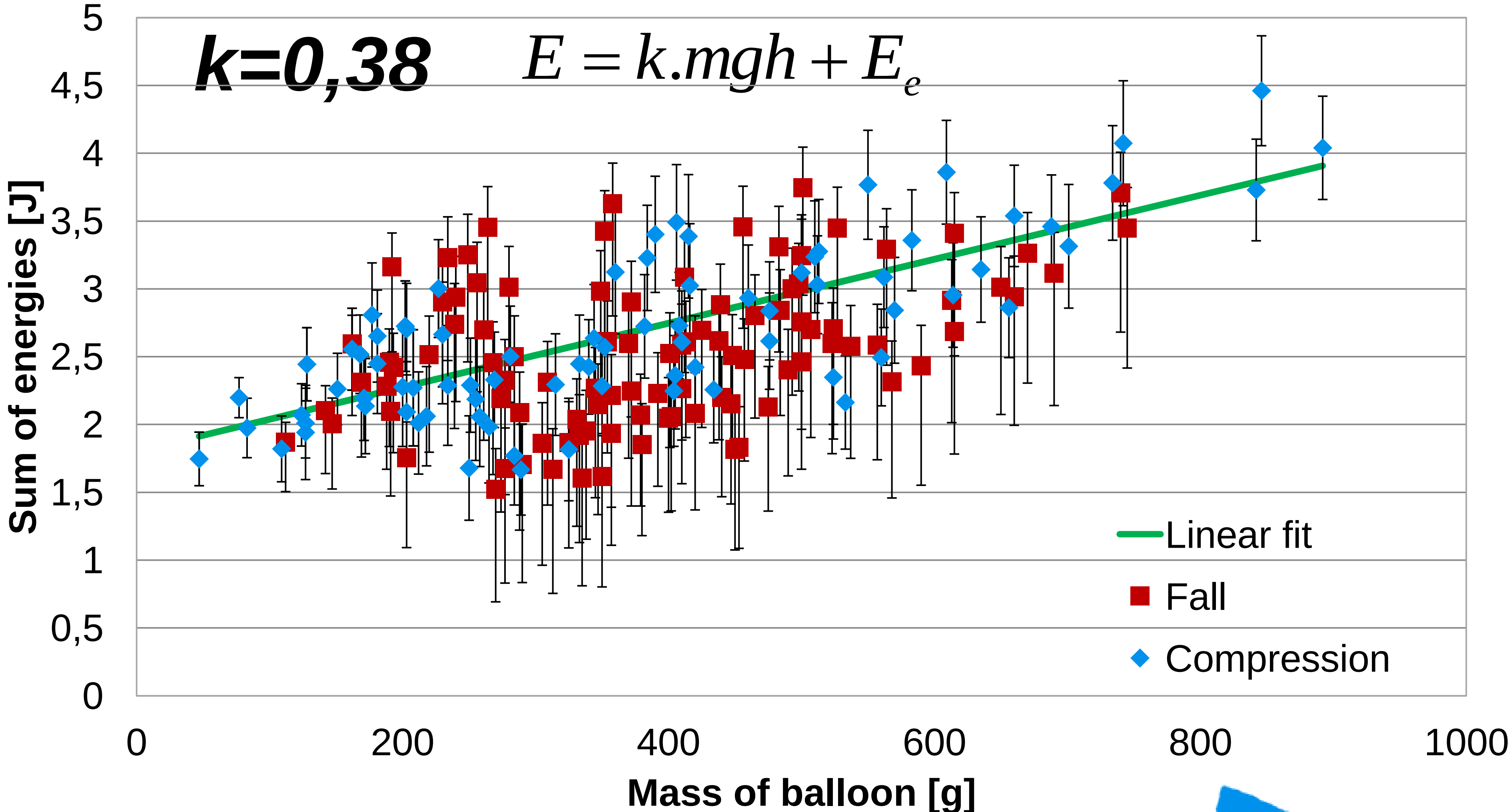


Thank you for your attention!



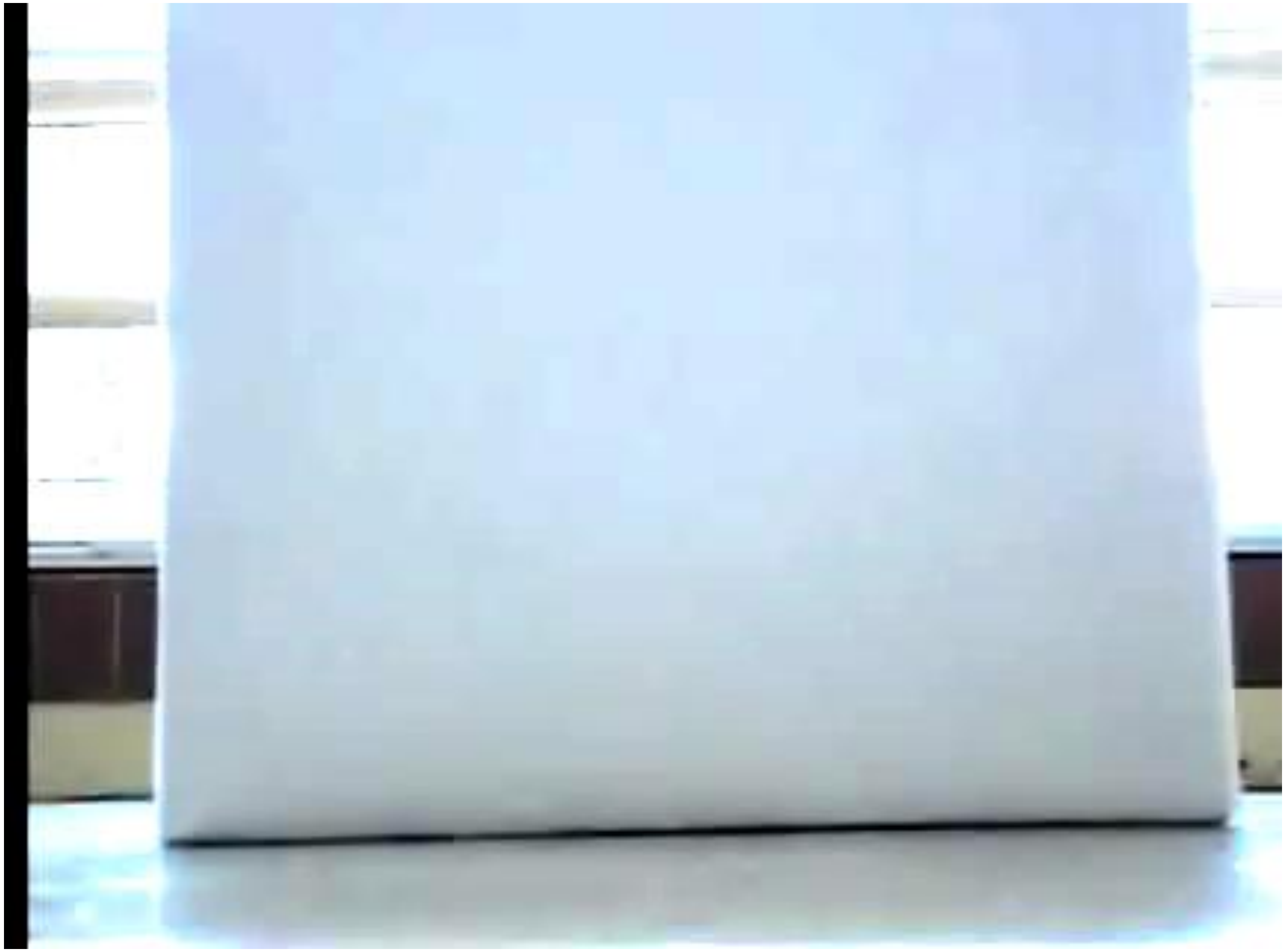
APPENDICES

Energy needed to **burst** trough **fall** & through **compression**

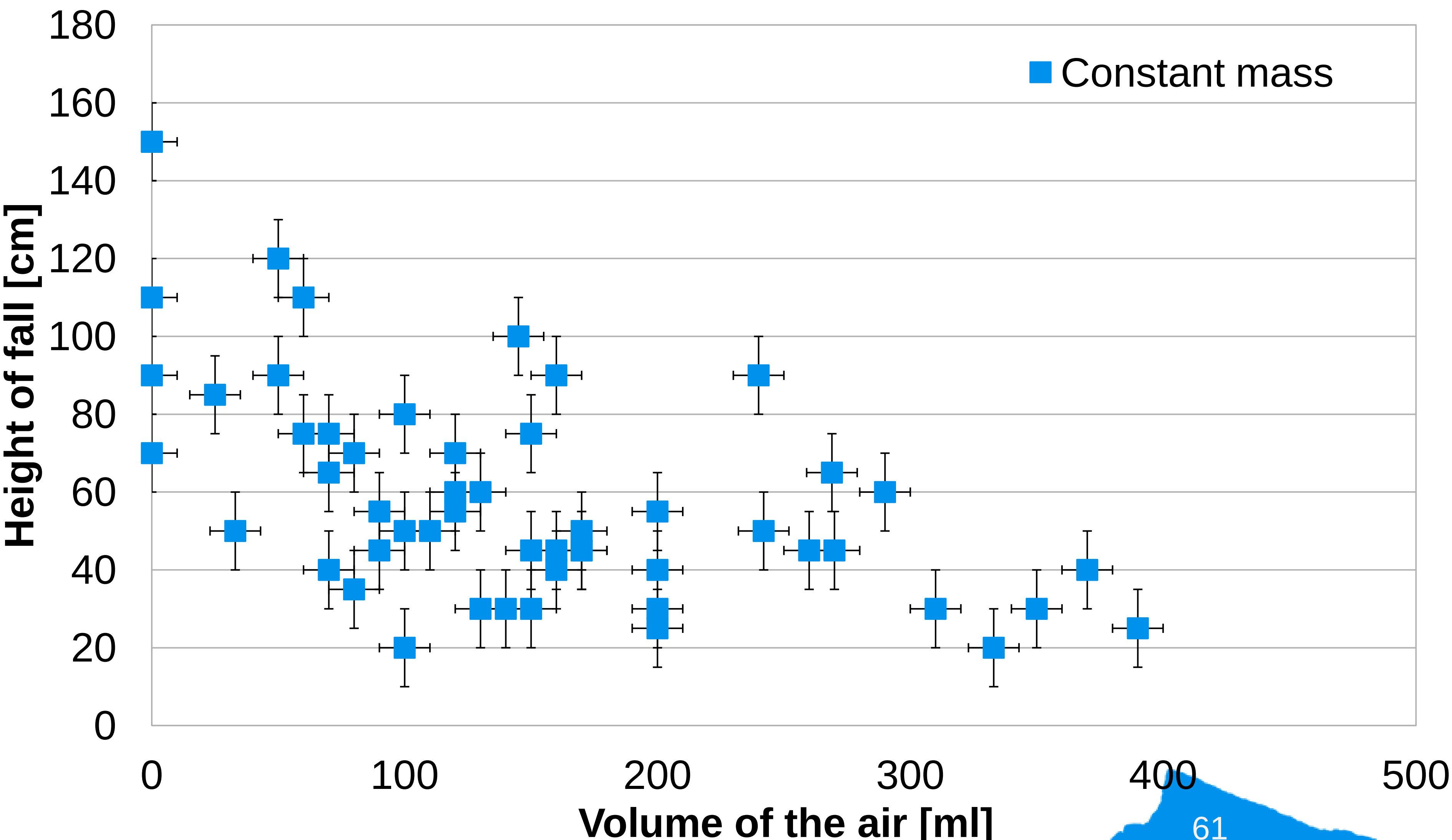


Rubber stretch at rebound

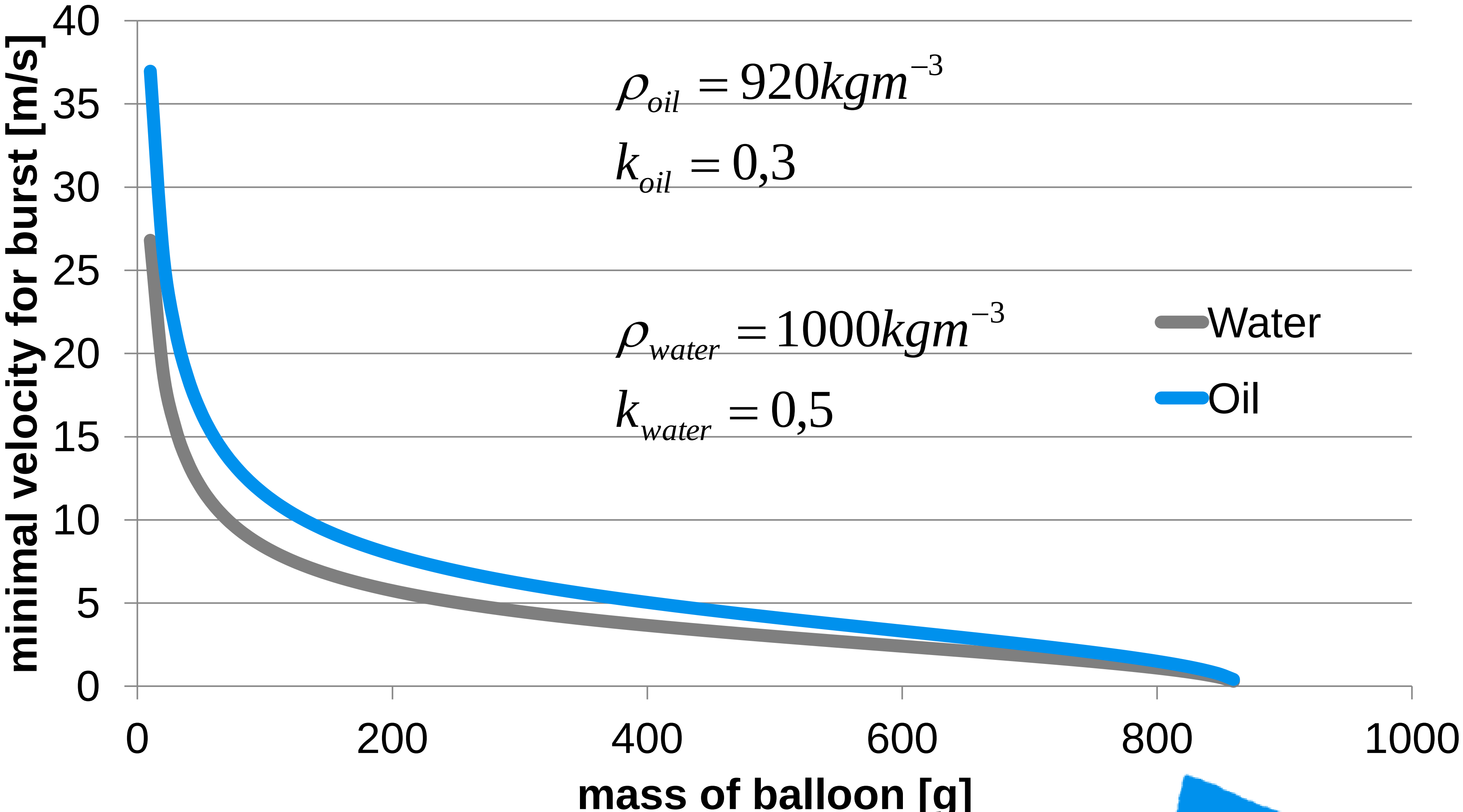
Rubber stretch at rebound



Adding air


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

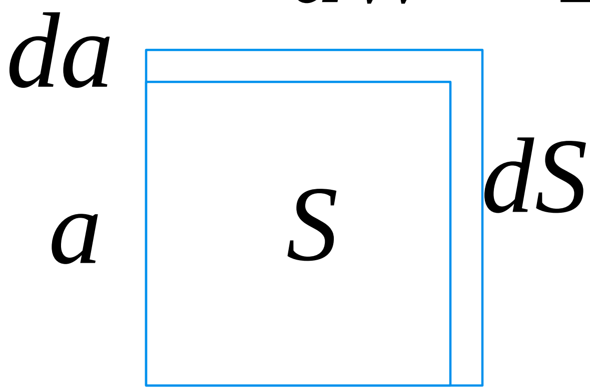
Other liquid



Elastic energy of the balloon

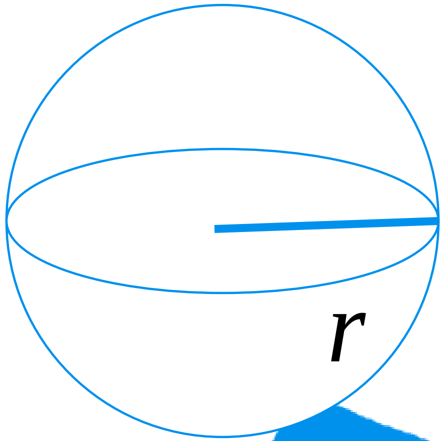
- Stretching a piece of rubber, surface tension σ

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



- 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 $= \int pdV$