Russia IYPT

Two balloons

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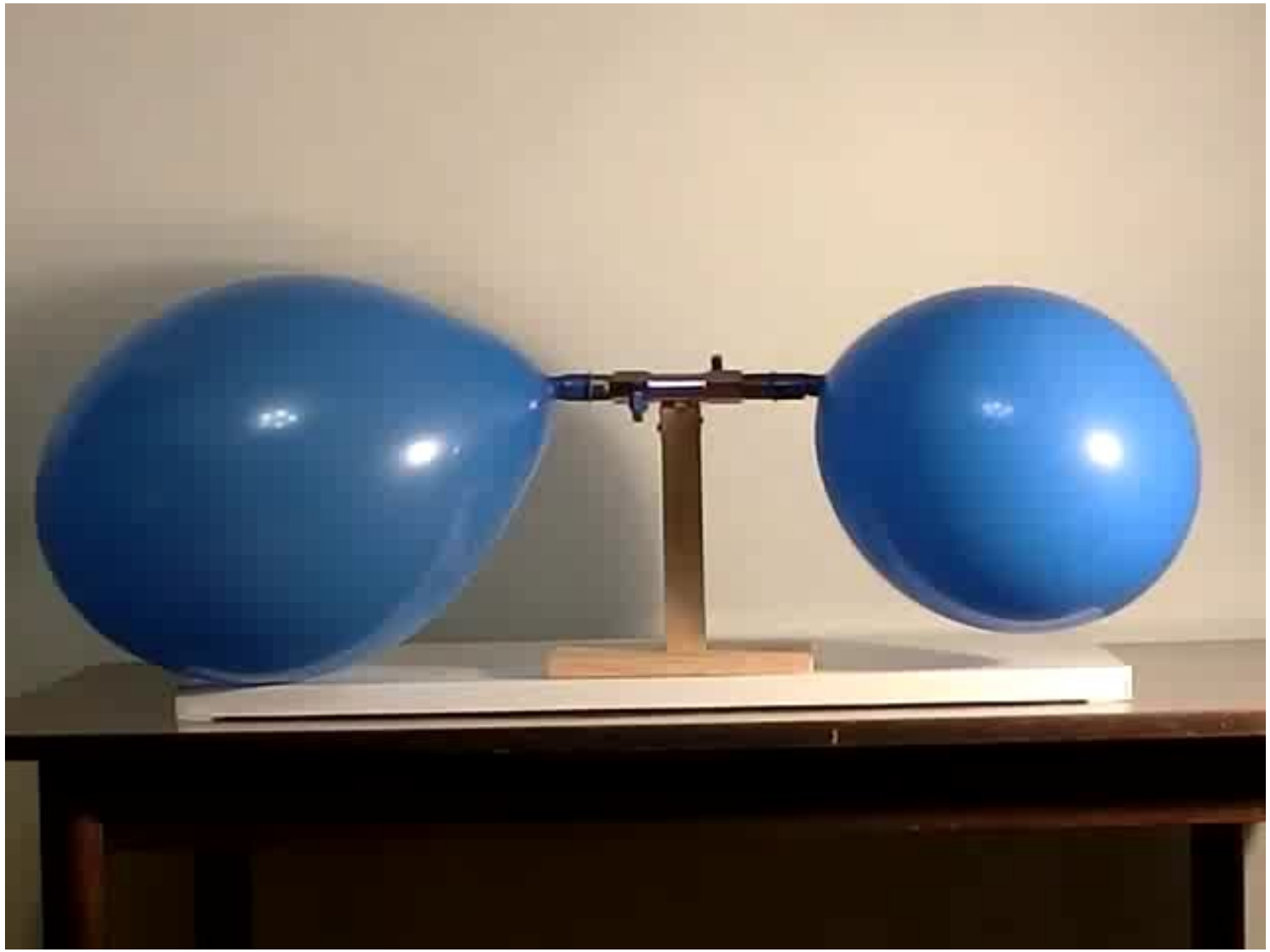
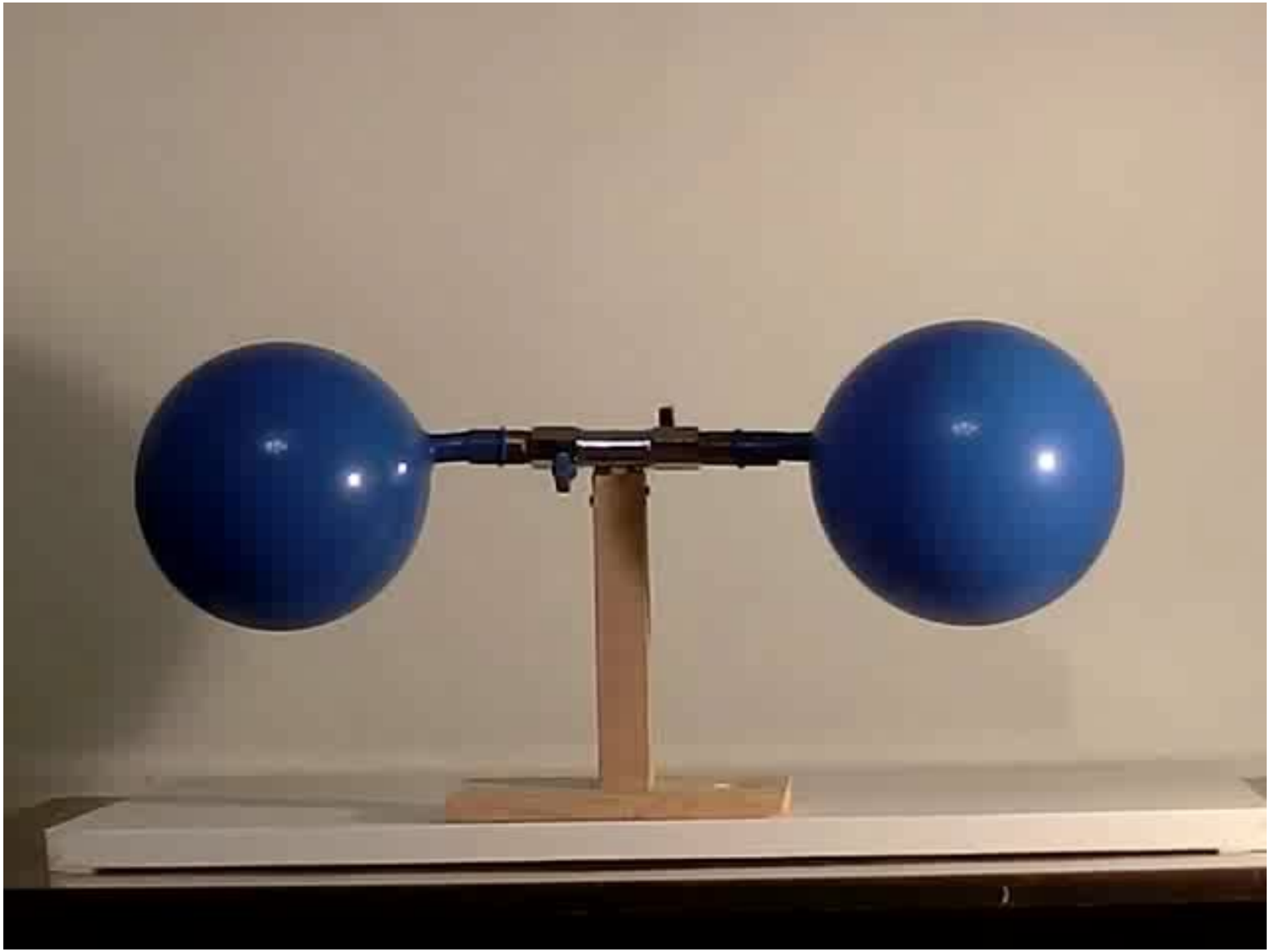
Problem

Two rubber balloons are partially inflated with air and connected together by a hose with valve. It's found that depending on initial balloon volumes, the air can flow in different directions. Investigate this phenomenon.

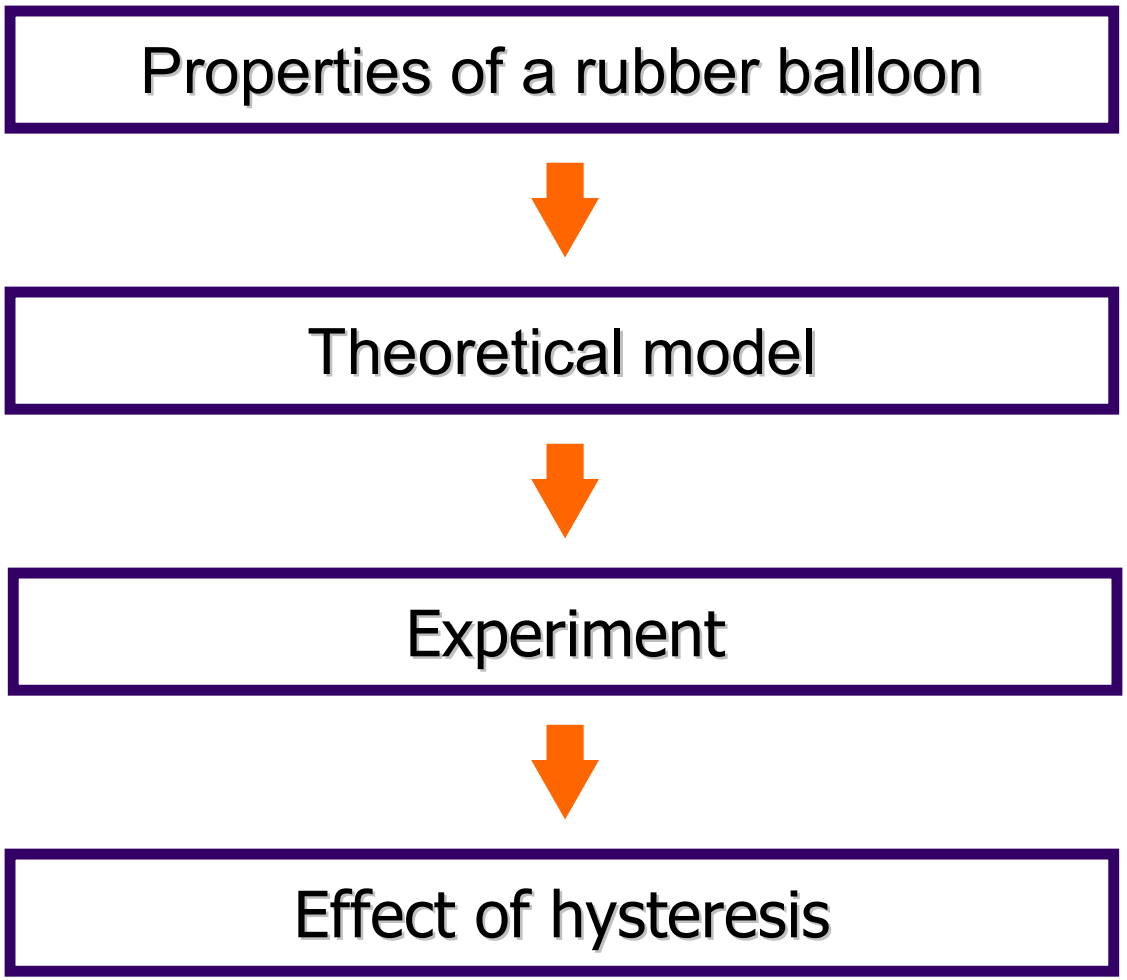
From a bigger to a smaller



From a smaller to a bigger

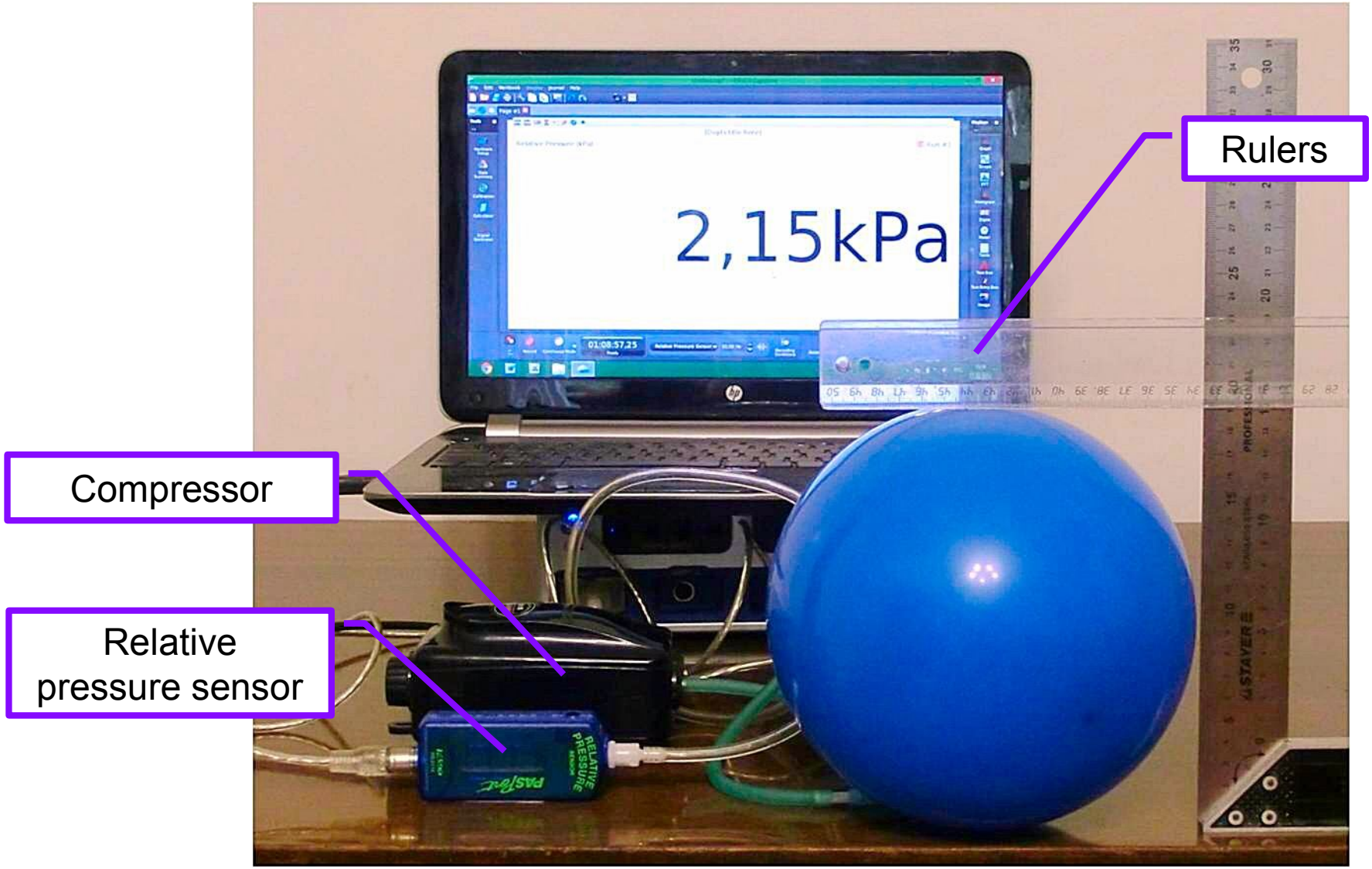


Outline of the report

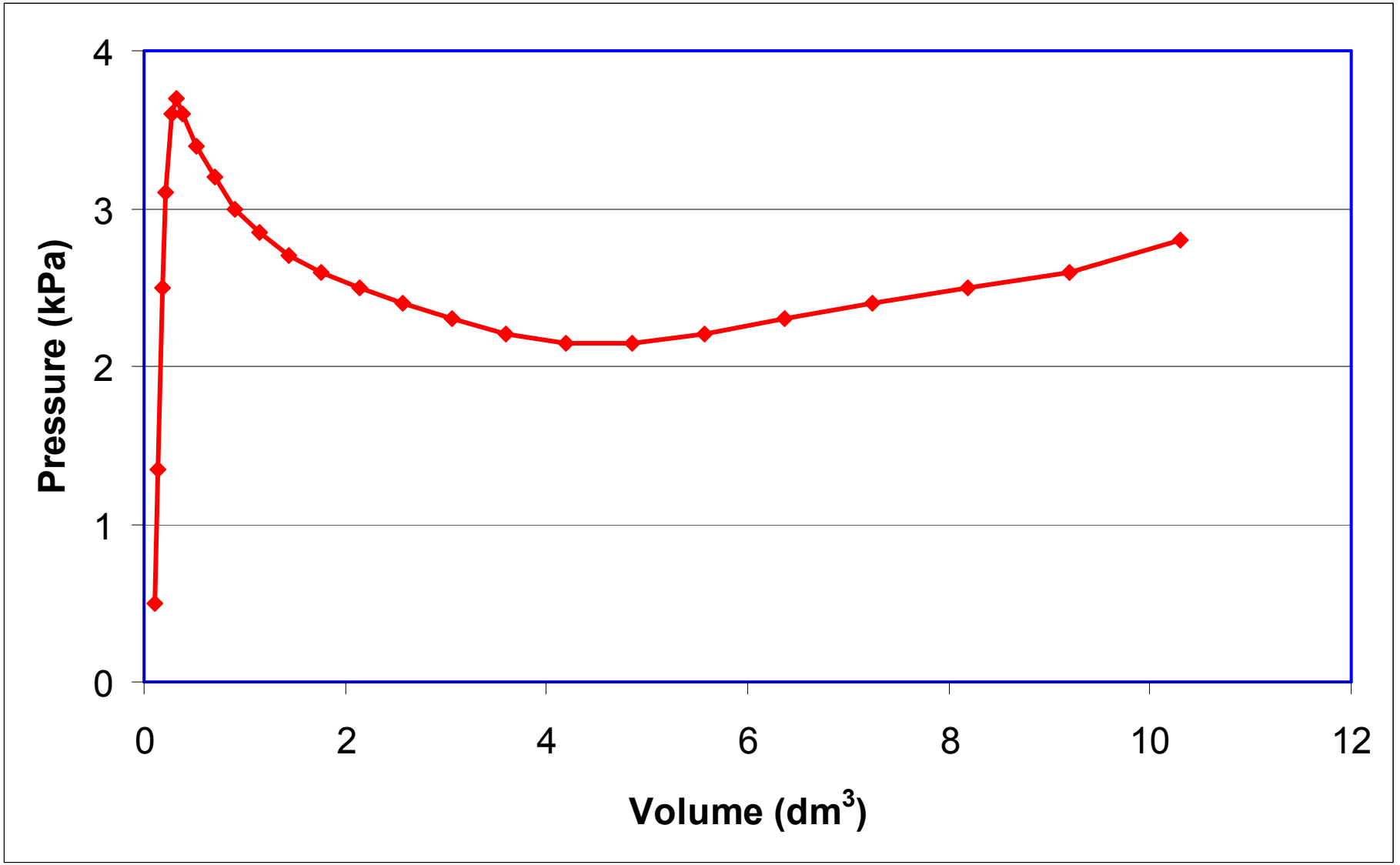


Properties of a rubber balloon

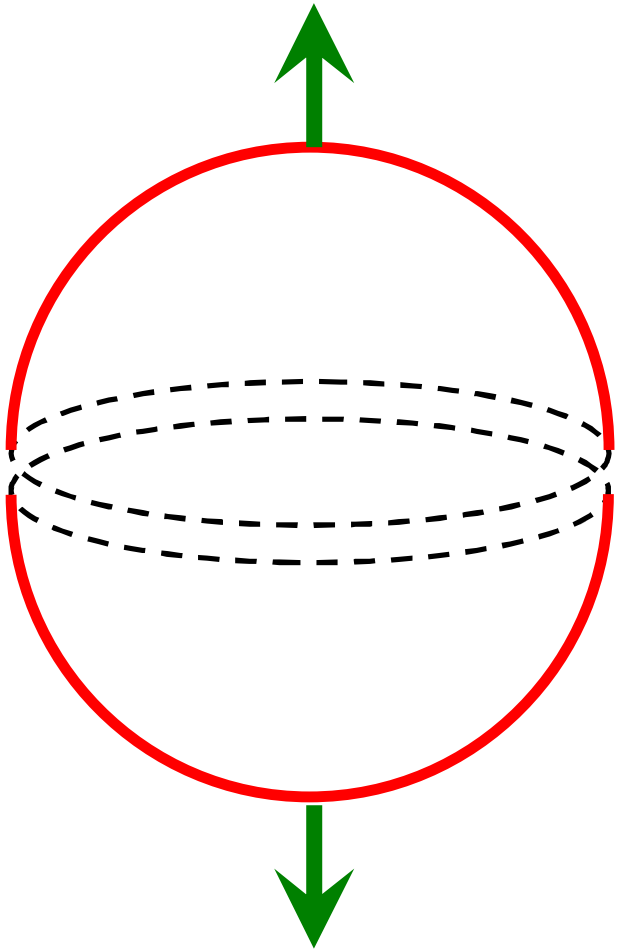
Relative pressure measurement



Relative pressure vs. volume



Breakout force and surface tension



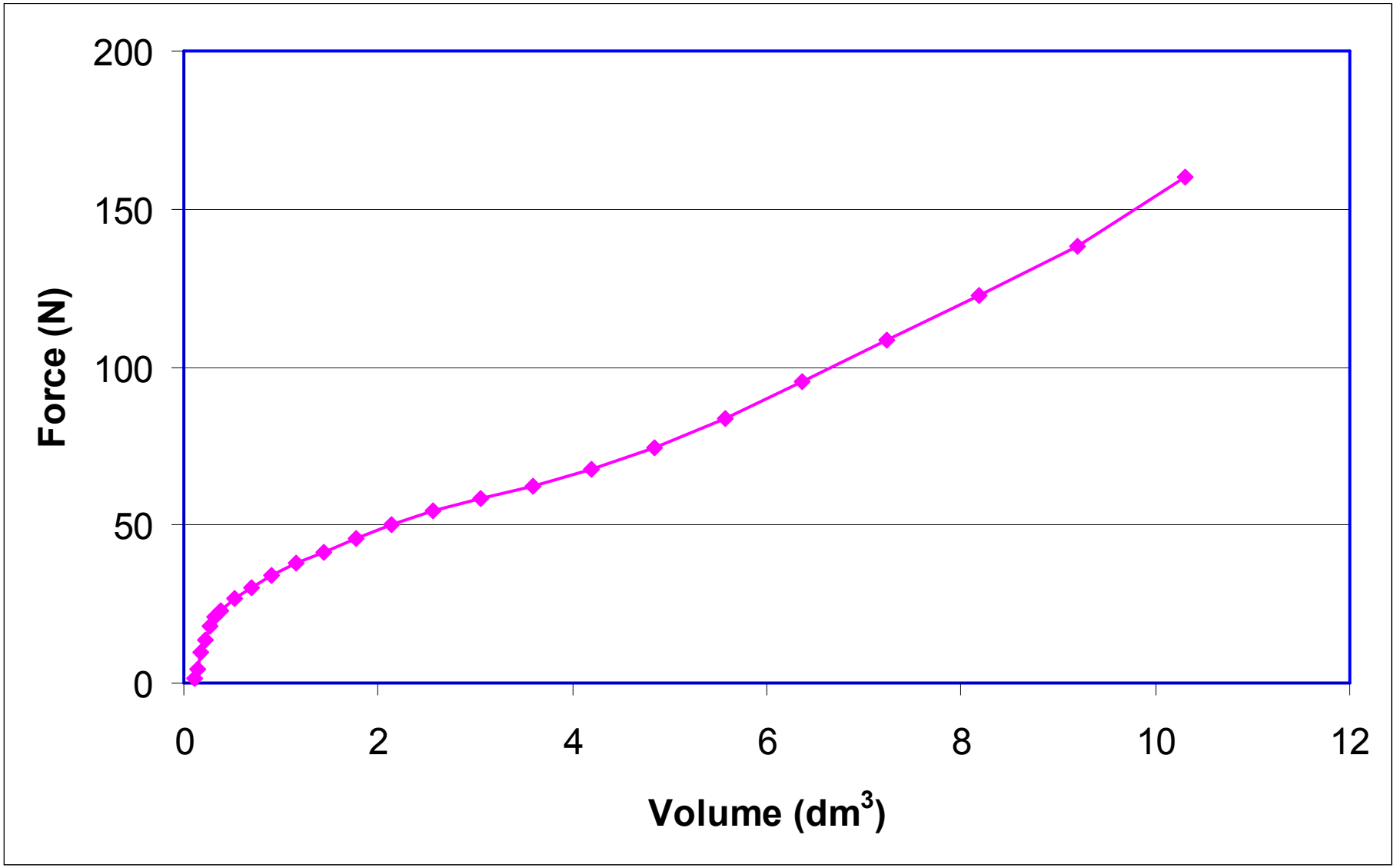
Breakout force

$$F = p \cdot \pi r^2$$

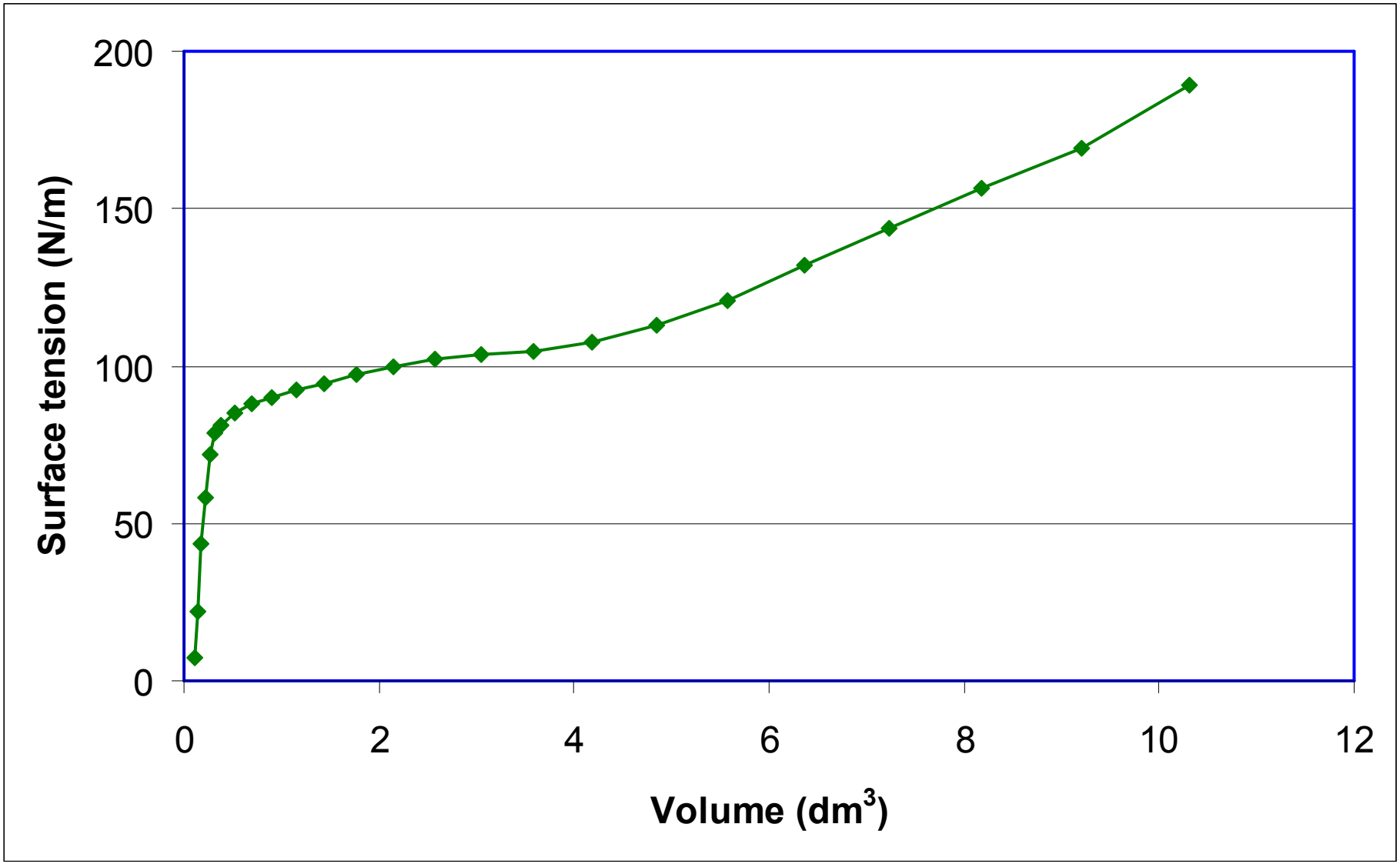
Surface tension

$$T = \frac{F}{2\pi r} = \frac{pr}{2}$$

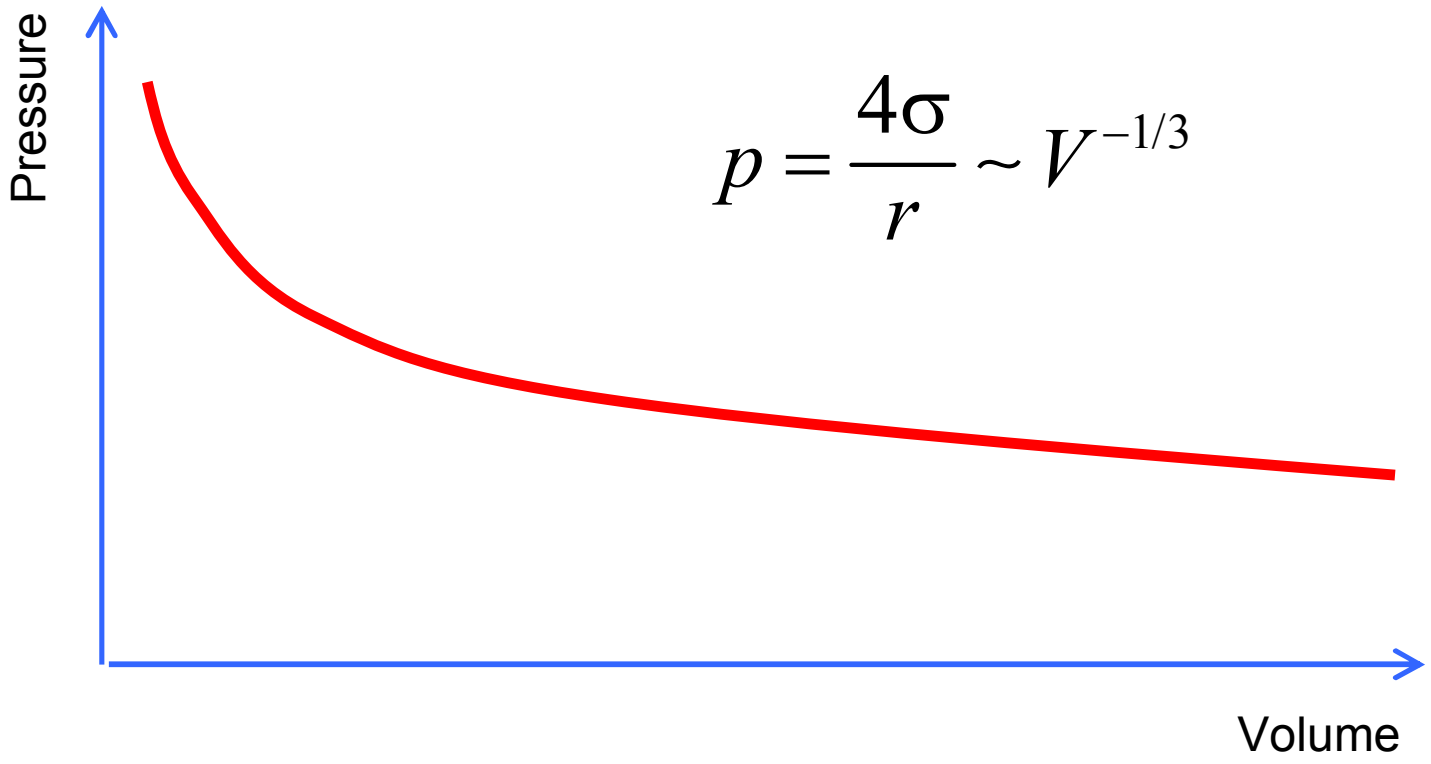
Force vs. volume



Surface tension vs. volume

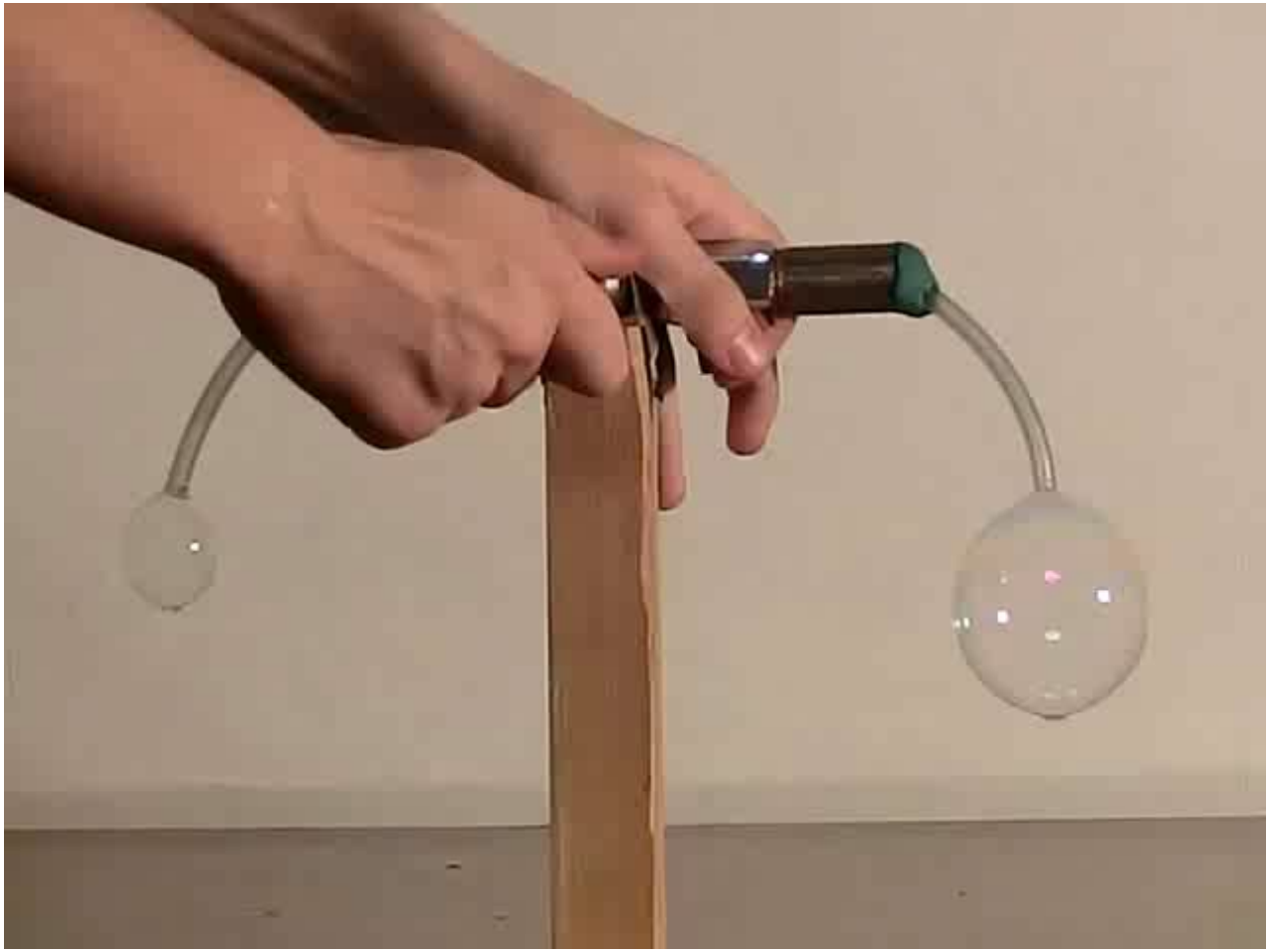


Constant surface tension

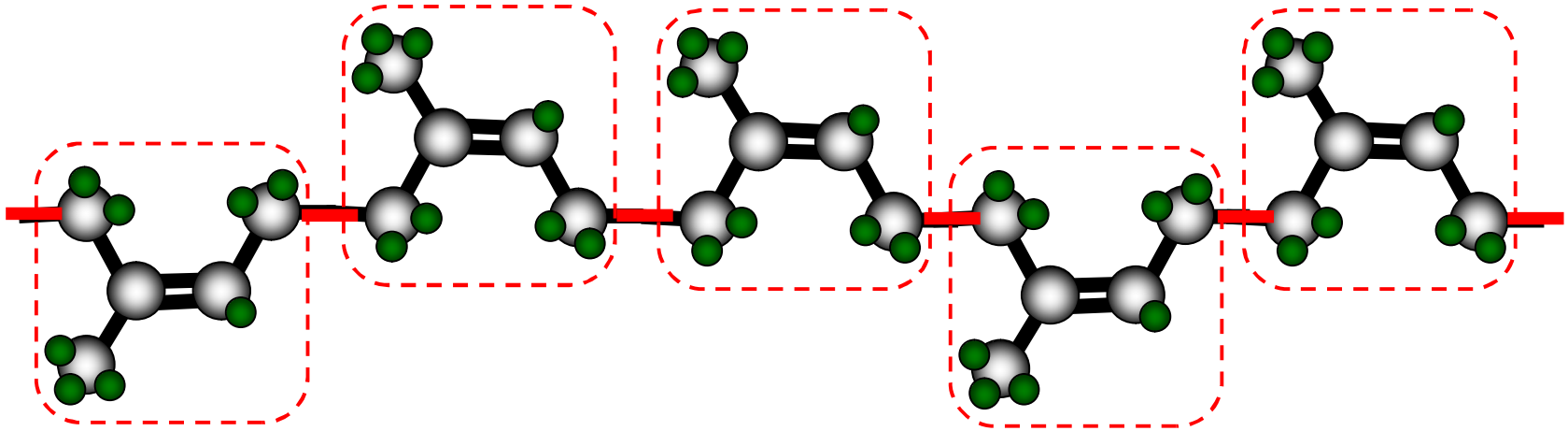


$$p = \frac{4\sigma}{r} \sim V^{-1/3}$$

Connected soap bubbles



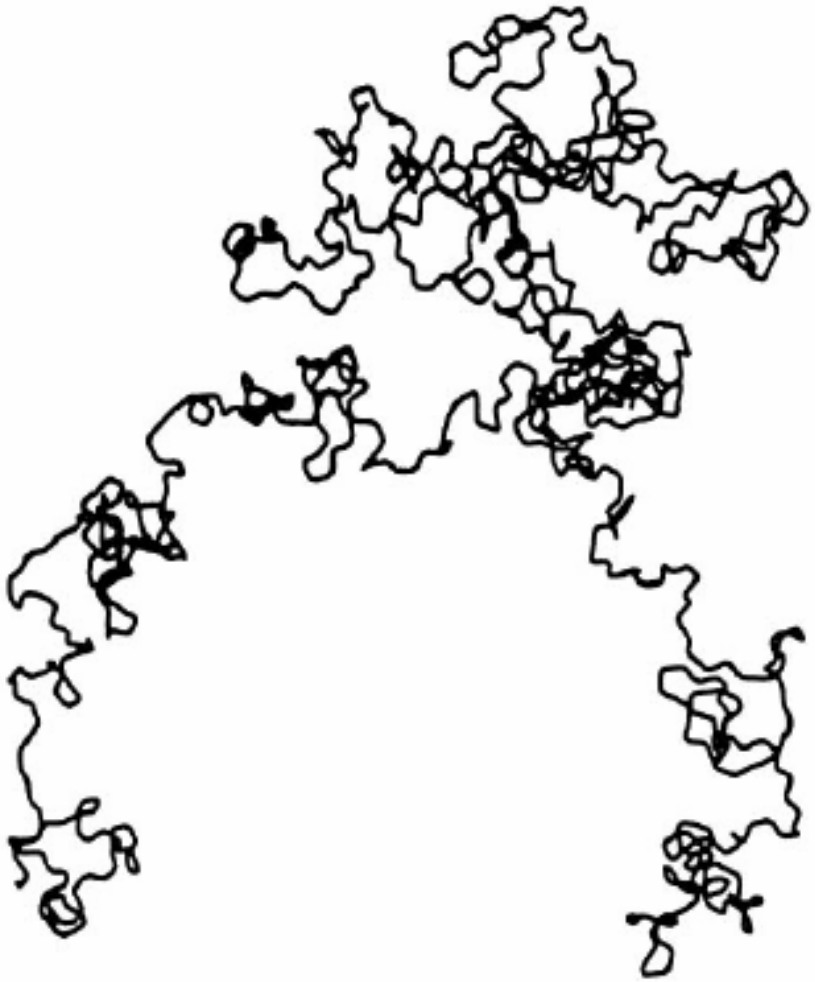
Molecular structure of rubber



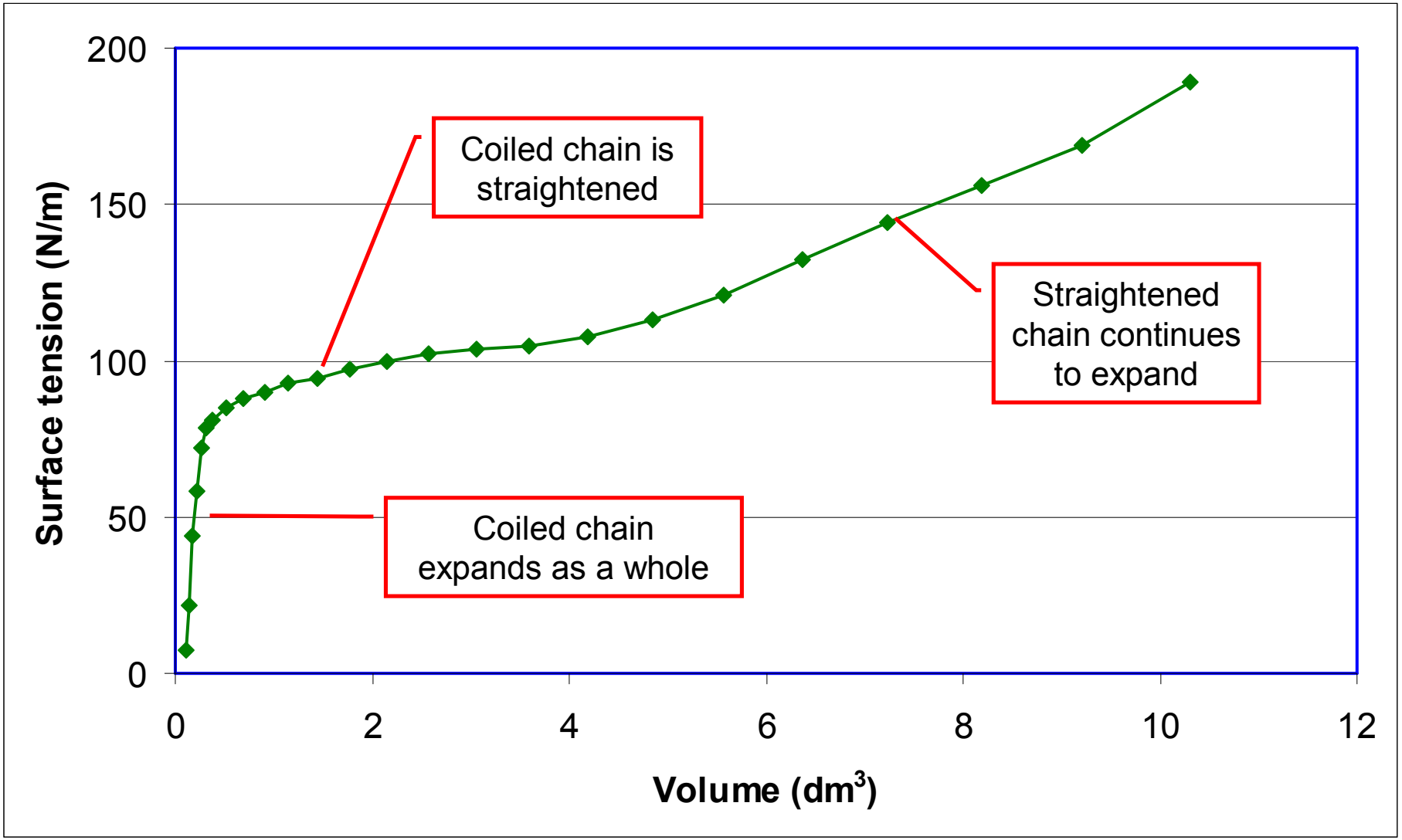
Isoprene polymer $(C_5H_8)_n$
with long molecular chains

Shape of a polymer chain

- Each block C_5H_8 rotates freely with respect to its neighbors. Therefore long molecular chains look like shown at this picture.
- The distance between the ends of a chain is much shorter than the length of this chain when it is straightened.

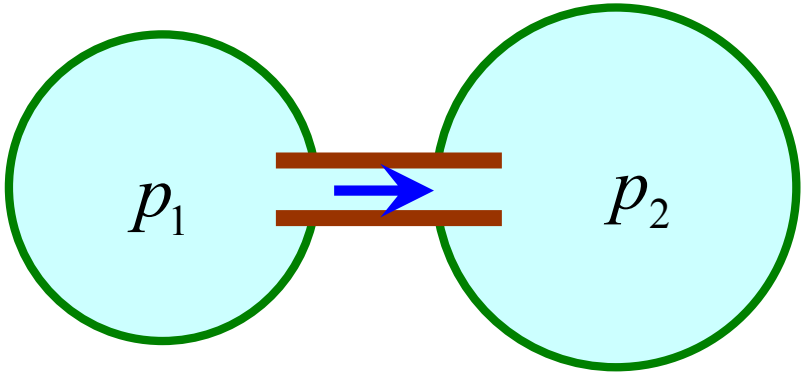


Surface tension vs. volume

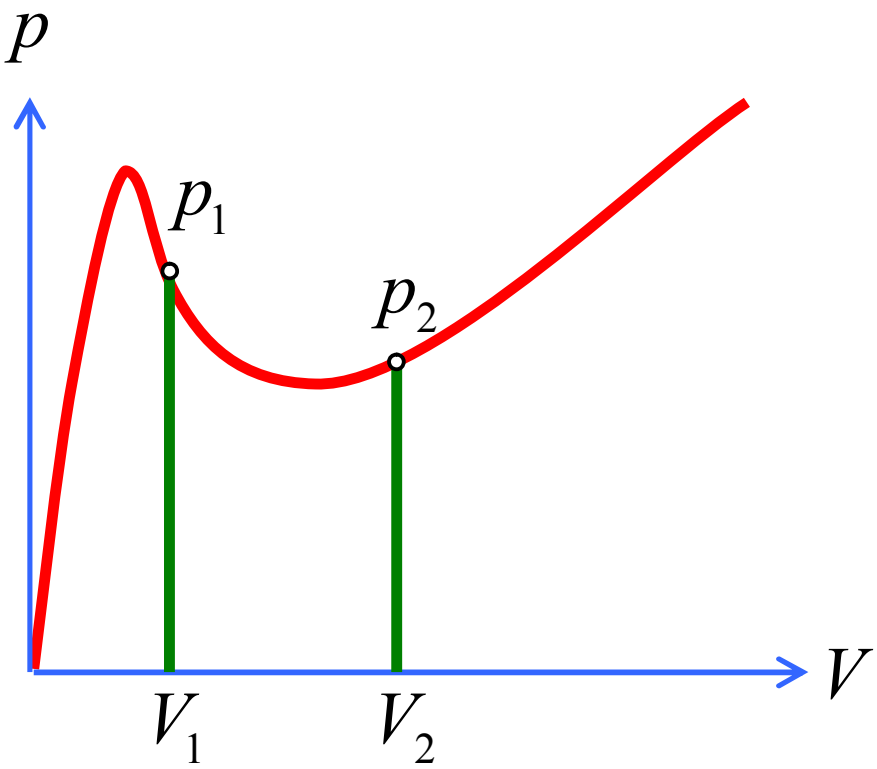


Connected balloons

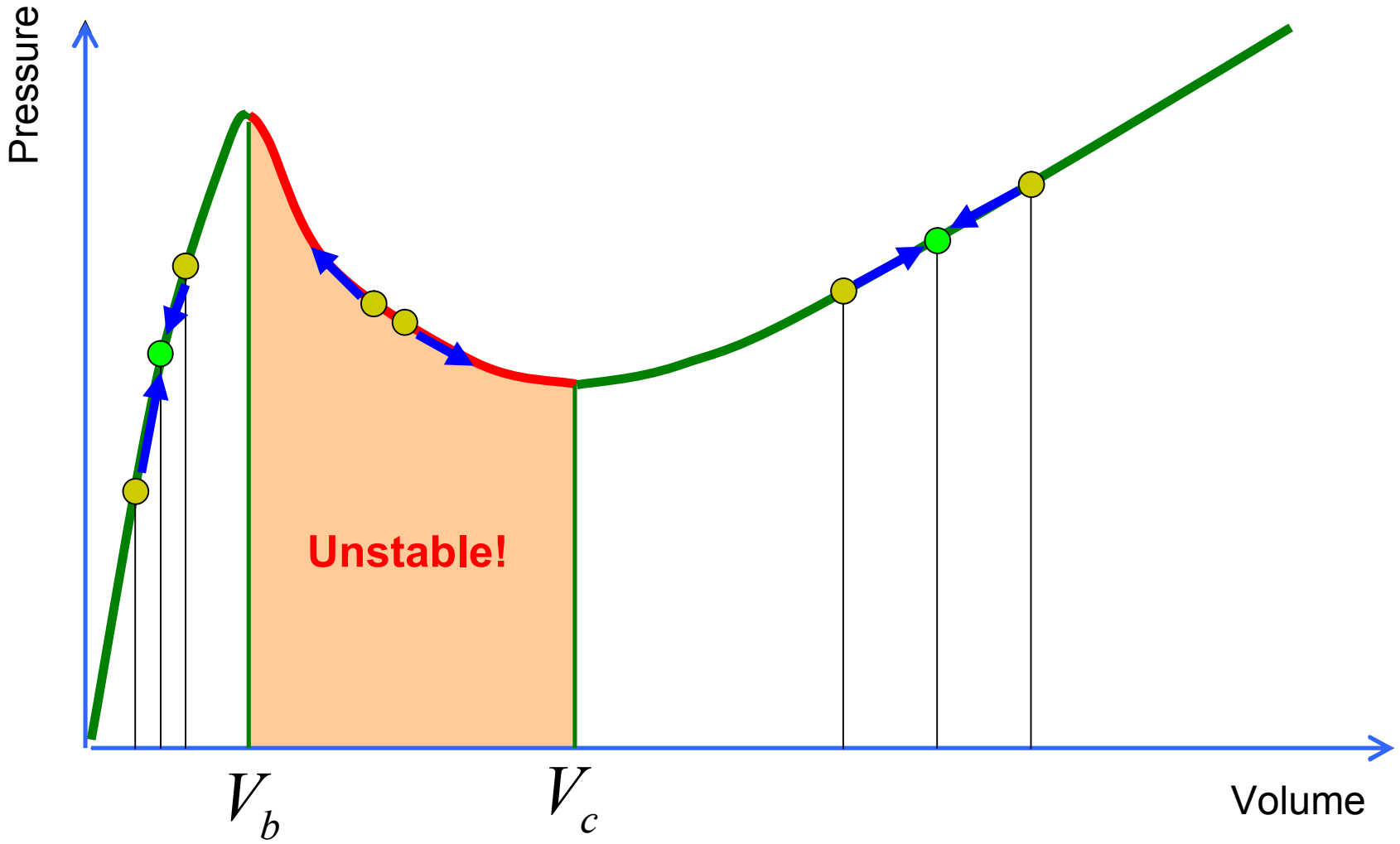
Flow direction



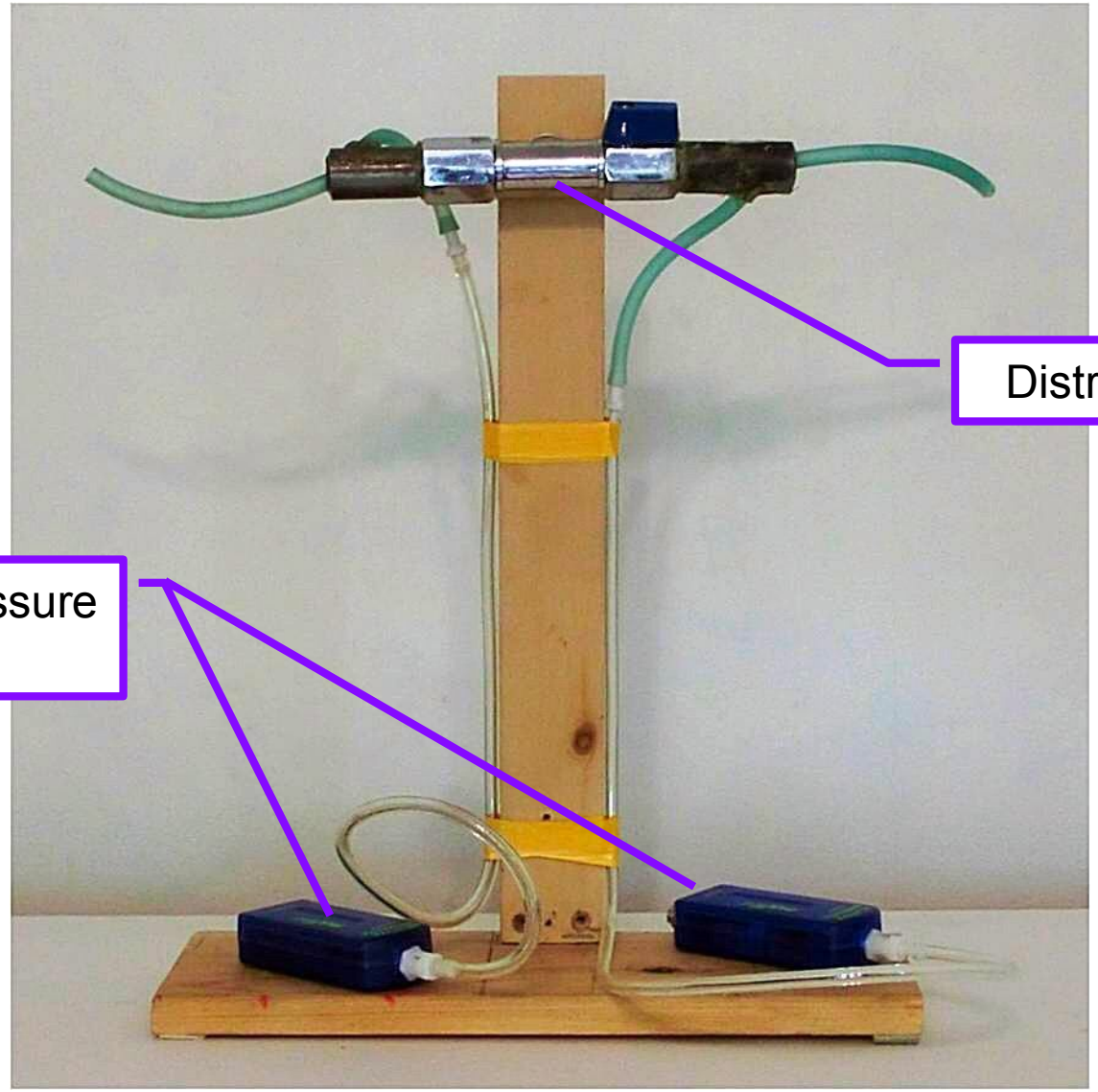
$p_1 > p_2$



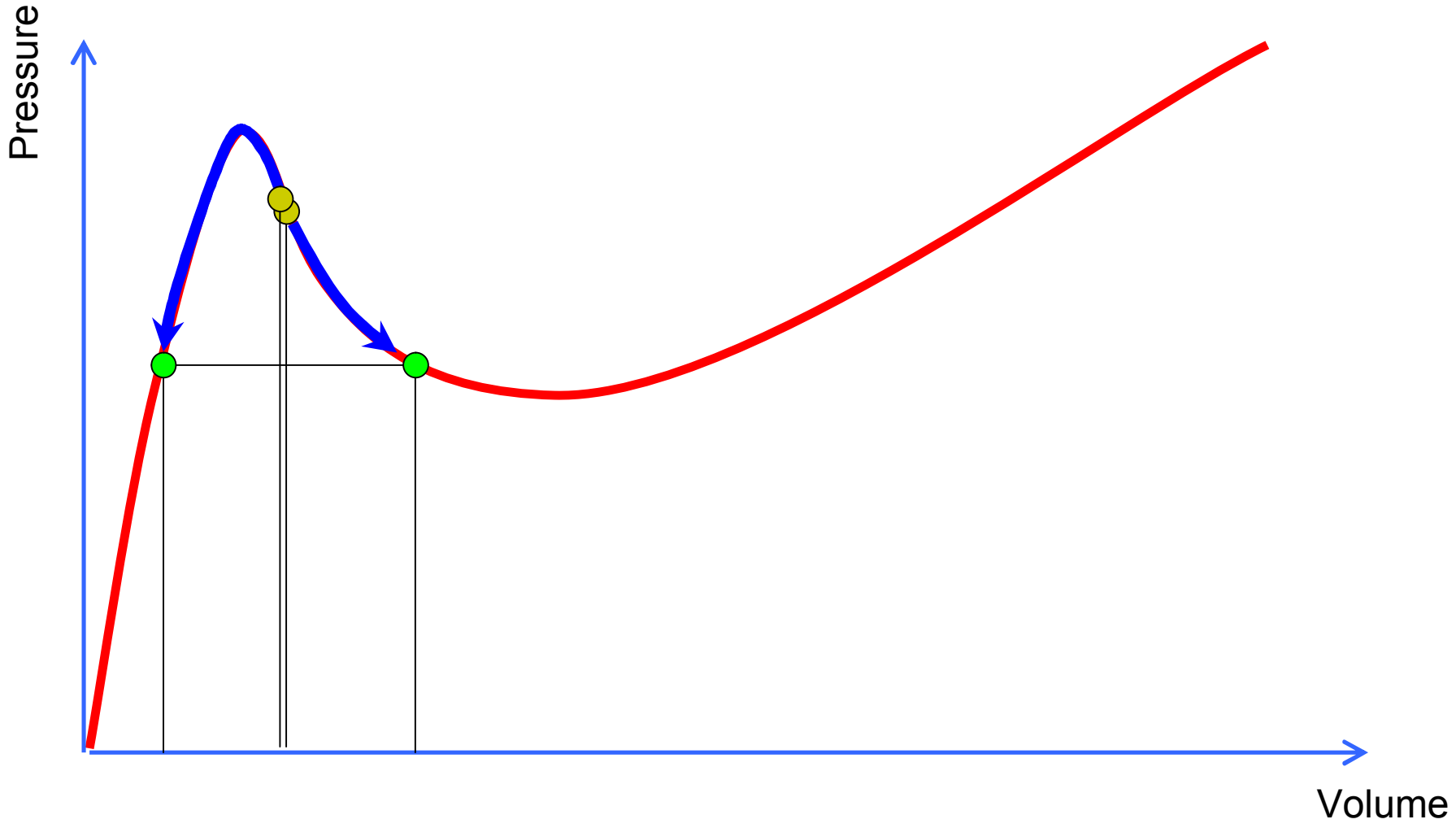
Stable and unstable branches



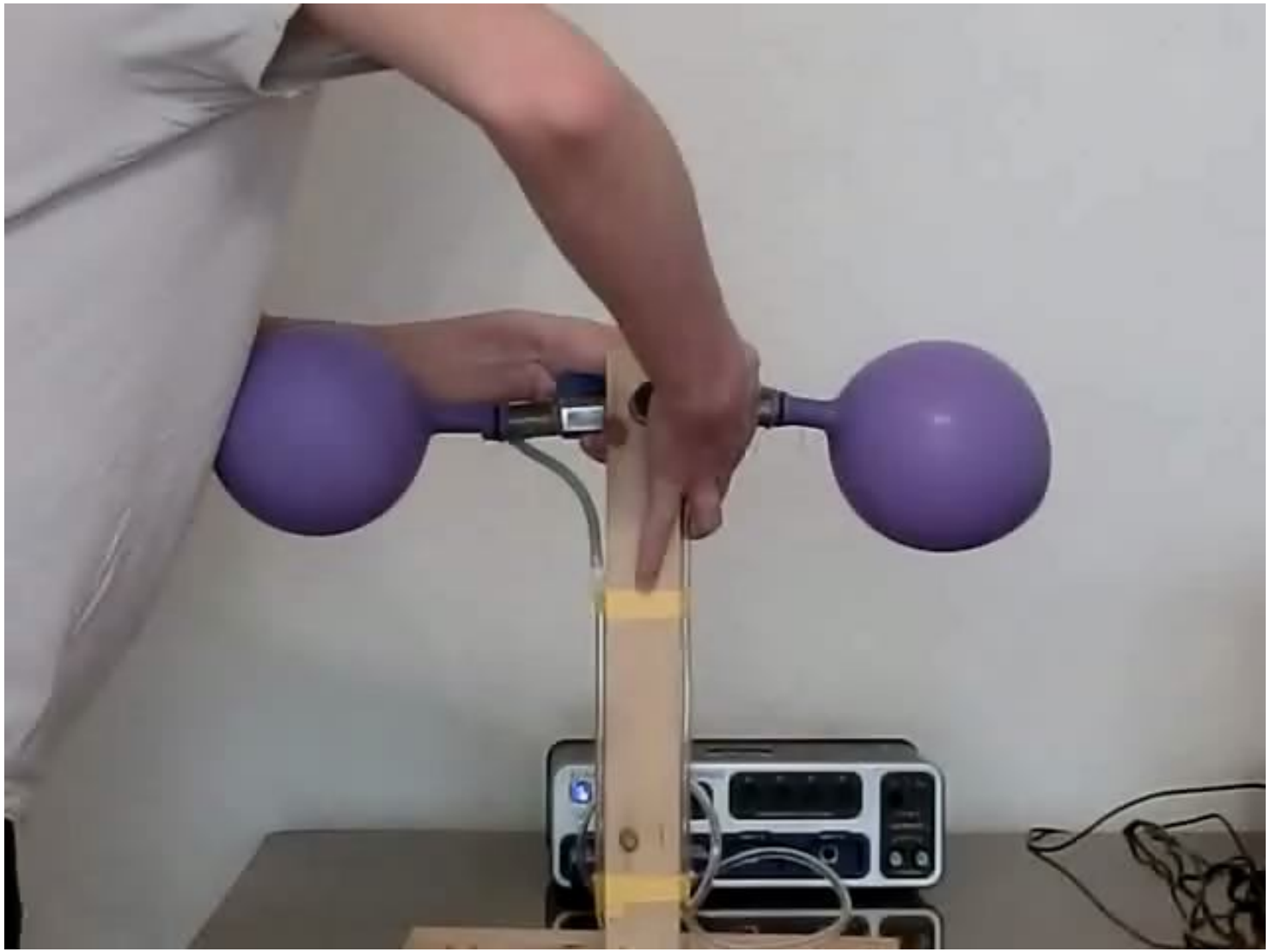
Experimental setup



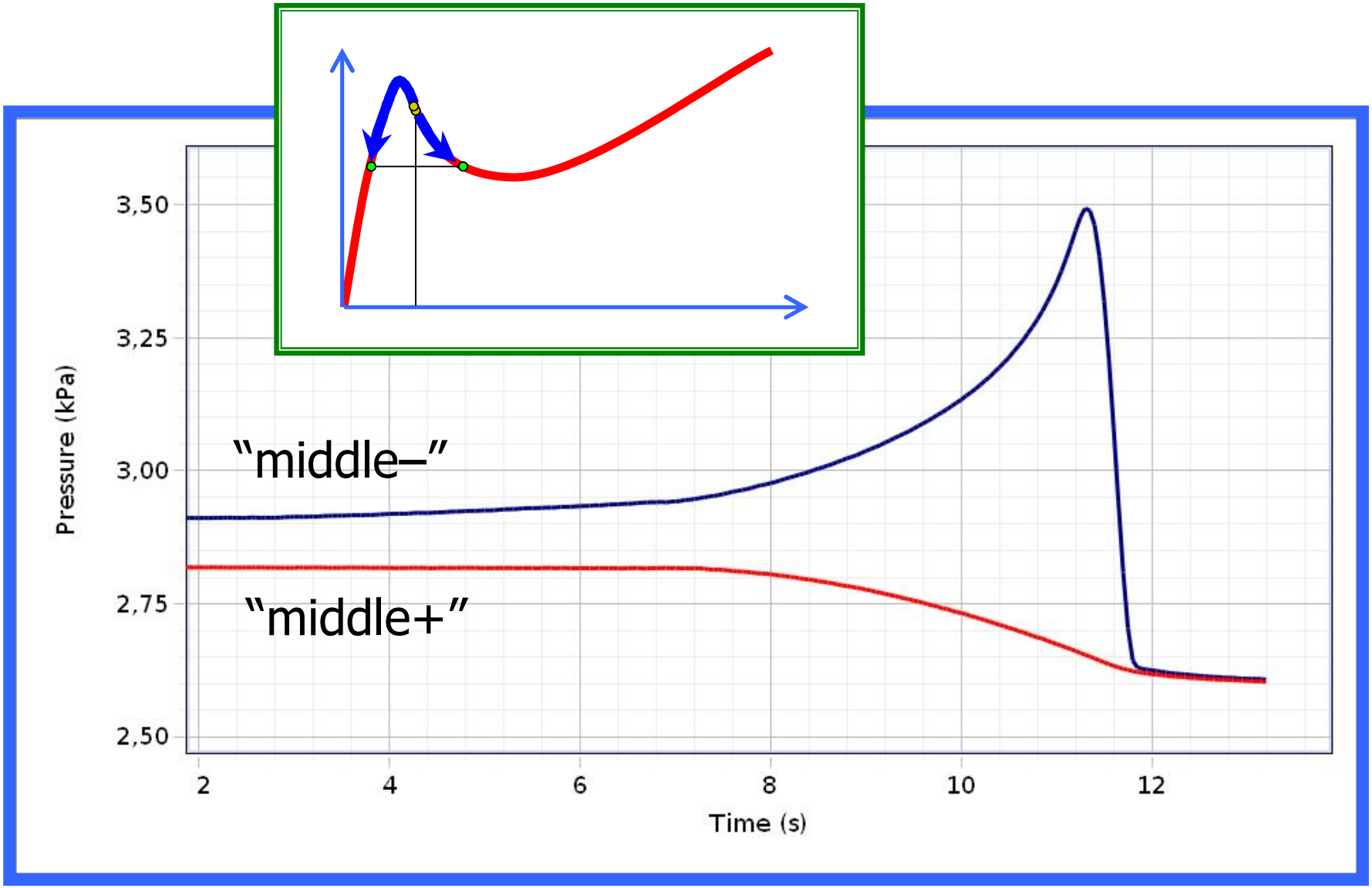
#1: Unstable equilibrium



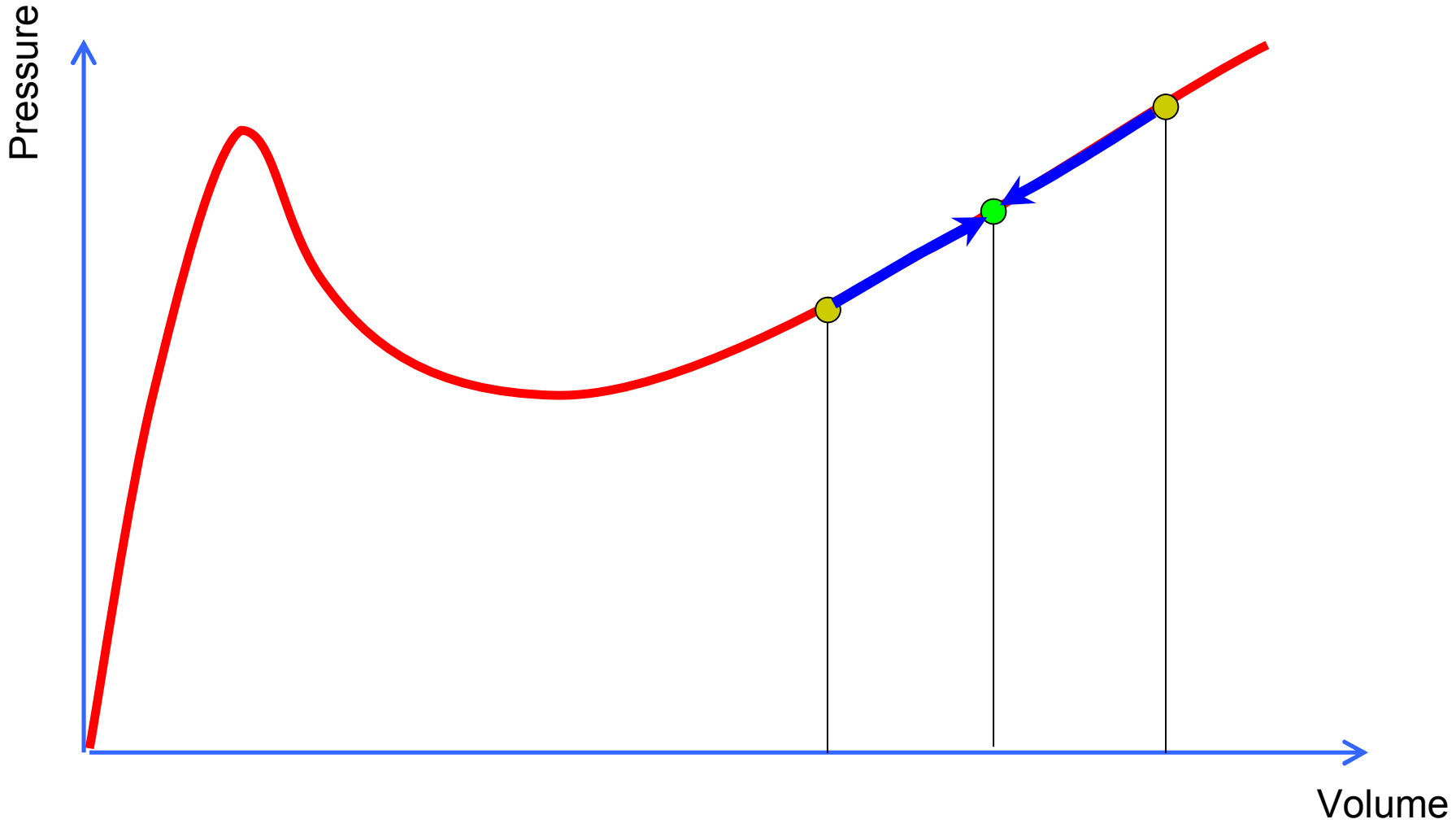
How it happens



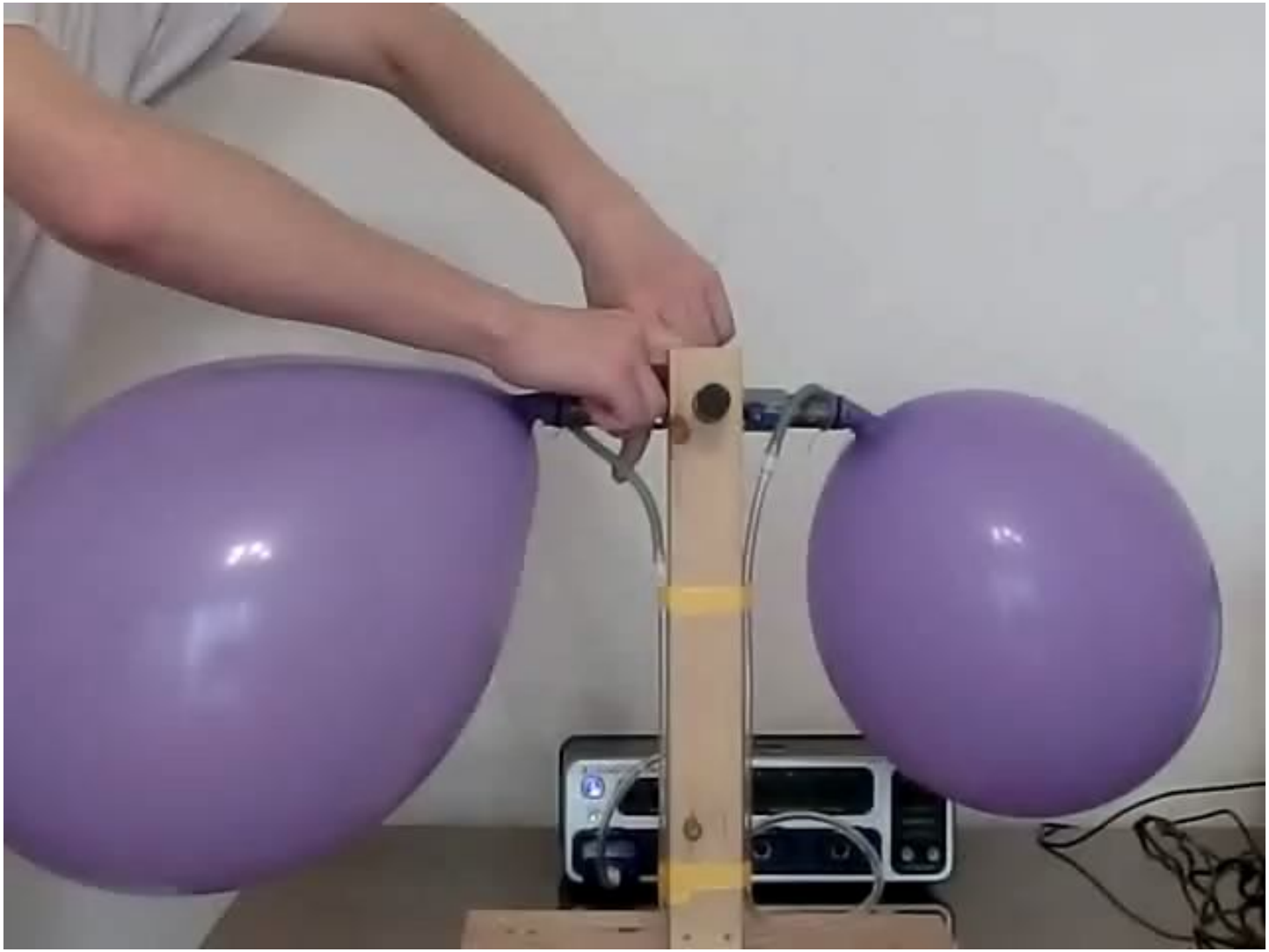
Relative pressure graph



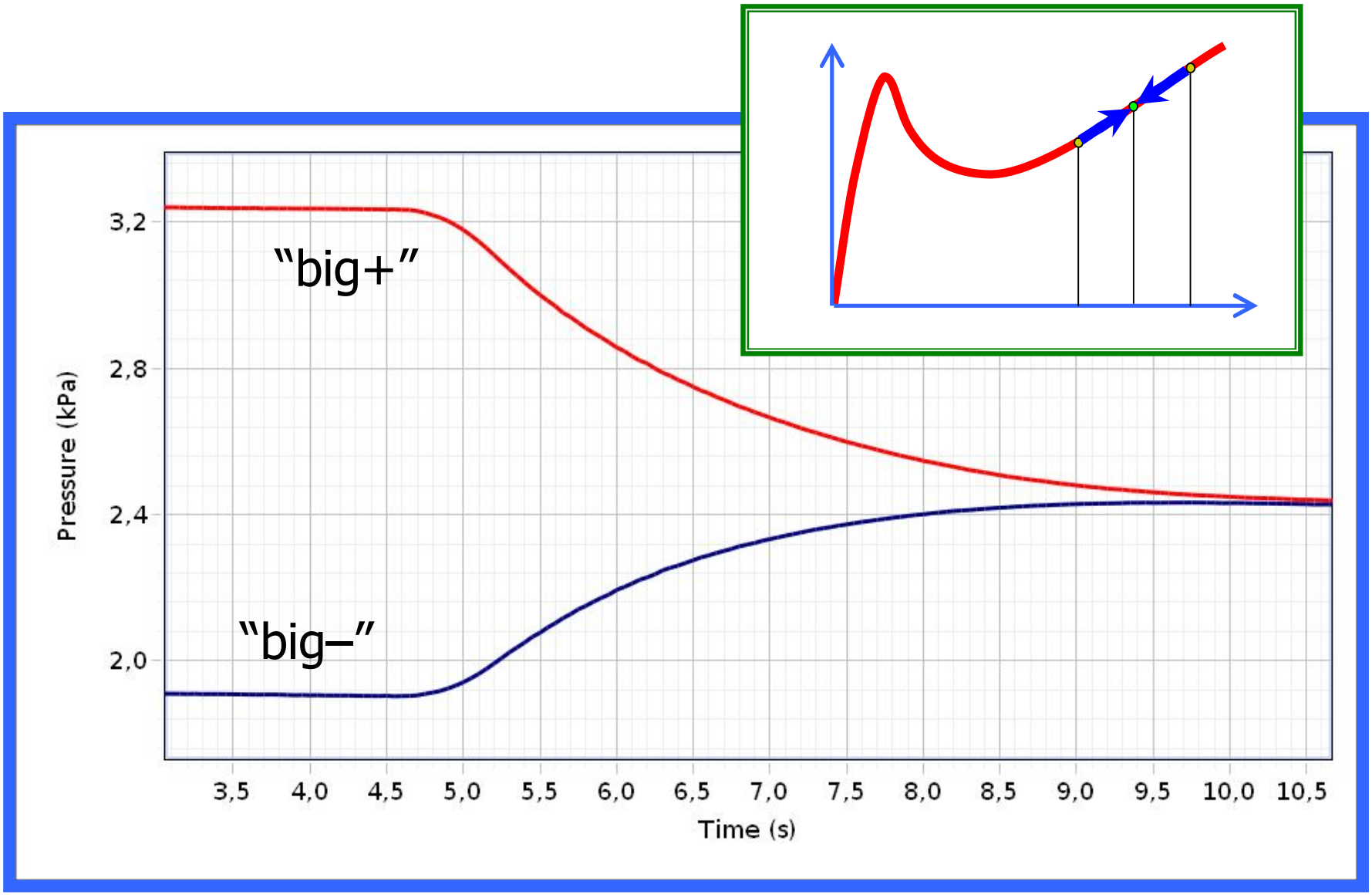
#2: Two big balloons



How it happens

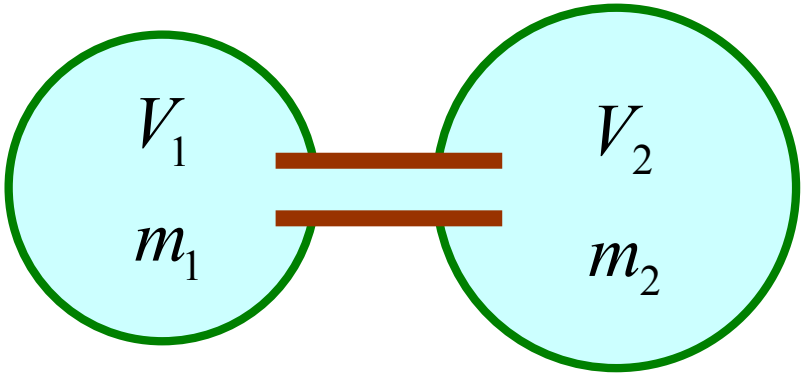


Relative pressure graph



Theoretical model

Total mass/volume is constant



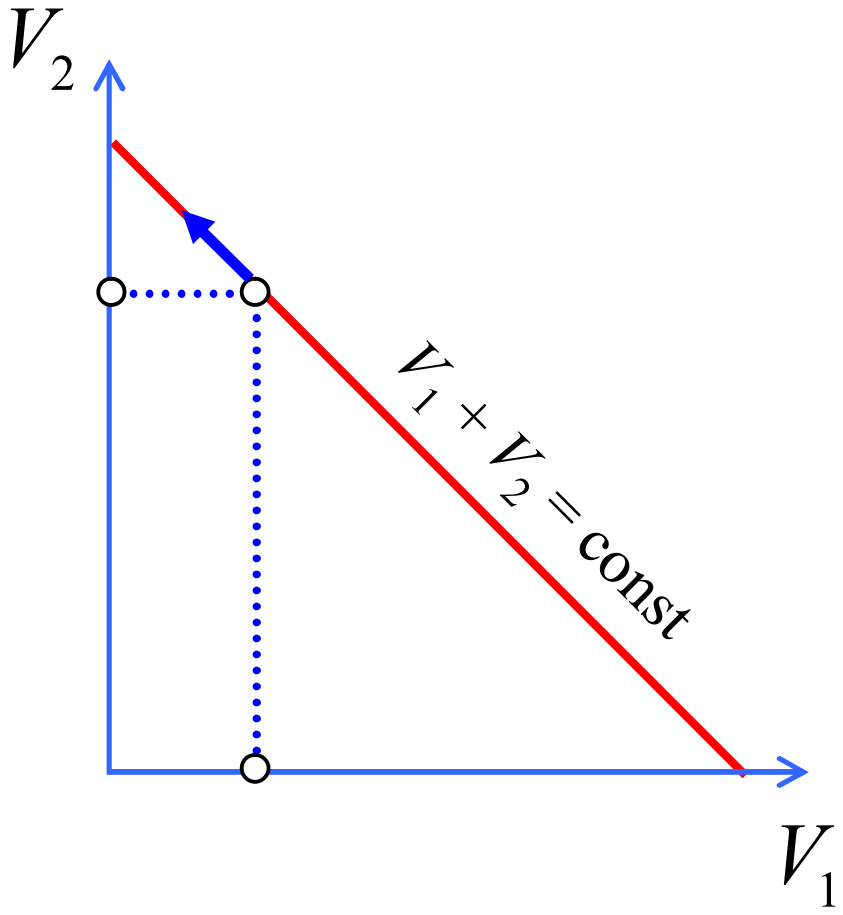
$$m_1 + m_2 = \text{const}$$

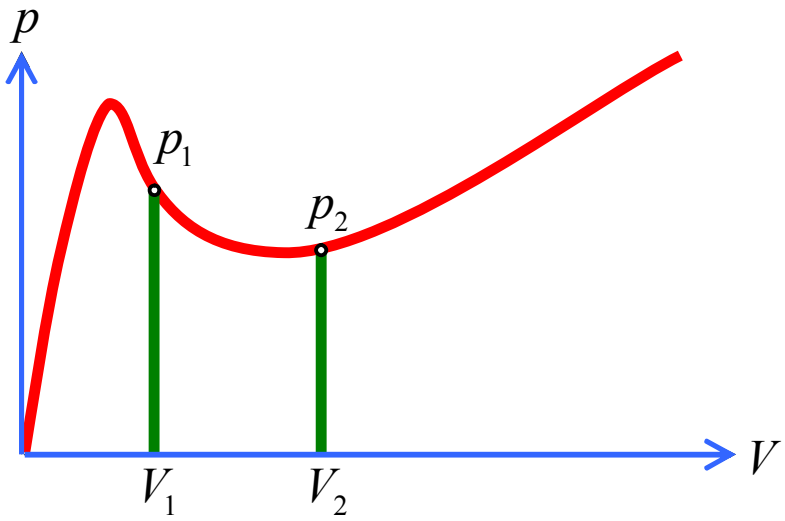
$$pV = \frac{m}{\mu} RT \quad \Rightarrow \quad V = \frac{m}{\mu} \cdot \frac{RT}{P}$$

$$\frac{\Delta p}{p} \le 0.02 \qquad \frac{\Delta T}{T} \le 0.01$$

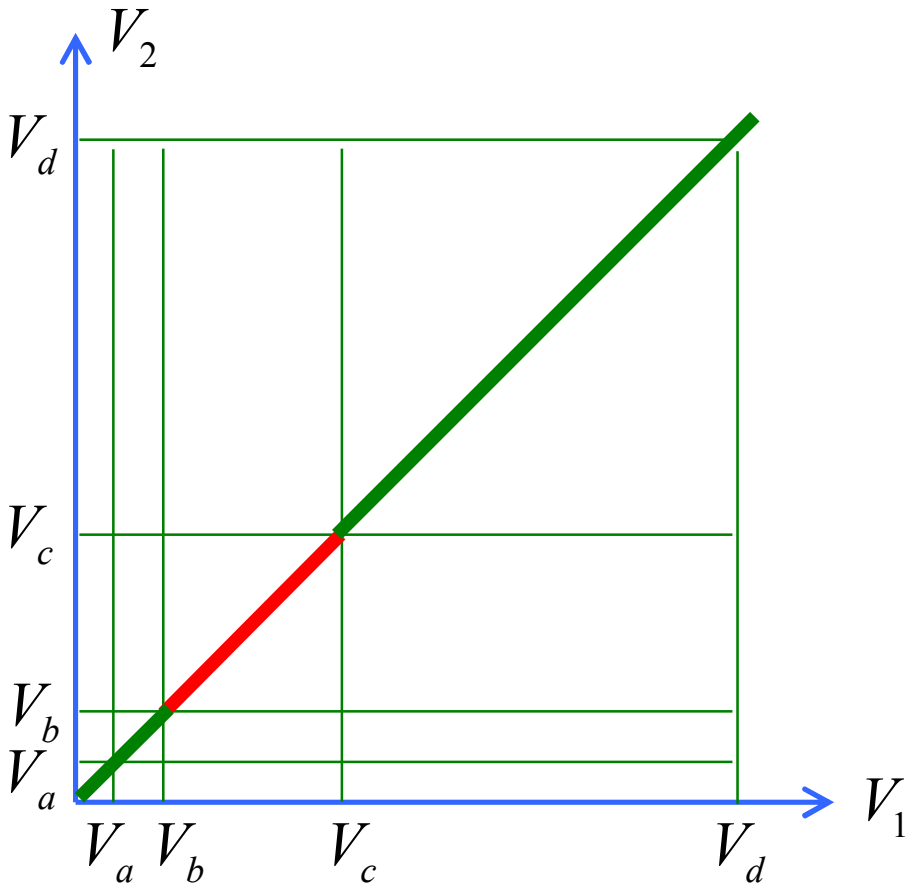
$$V_1 + V_2 = \text{const}$$

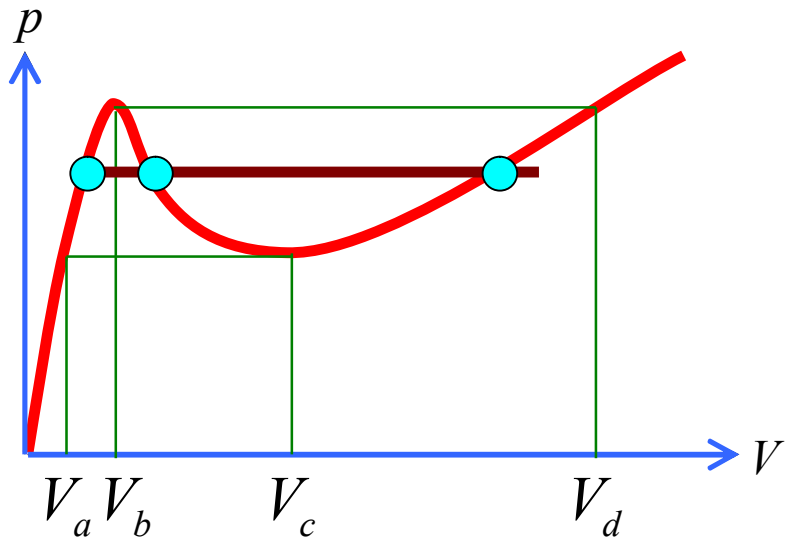
Phase diagram (analog)



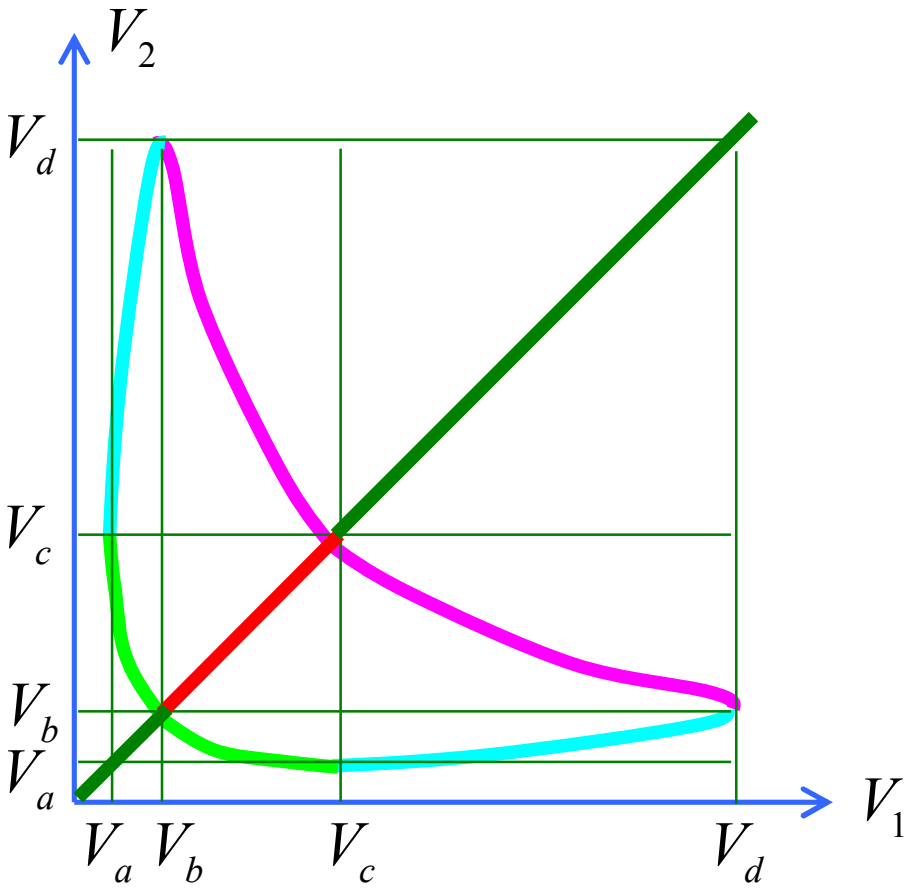


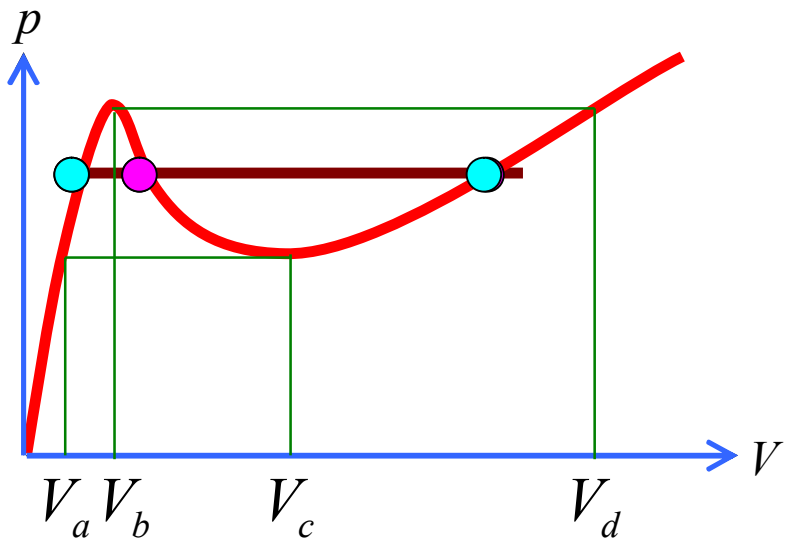
Additional marking



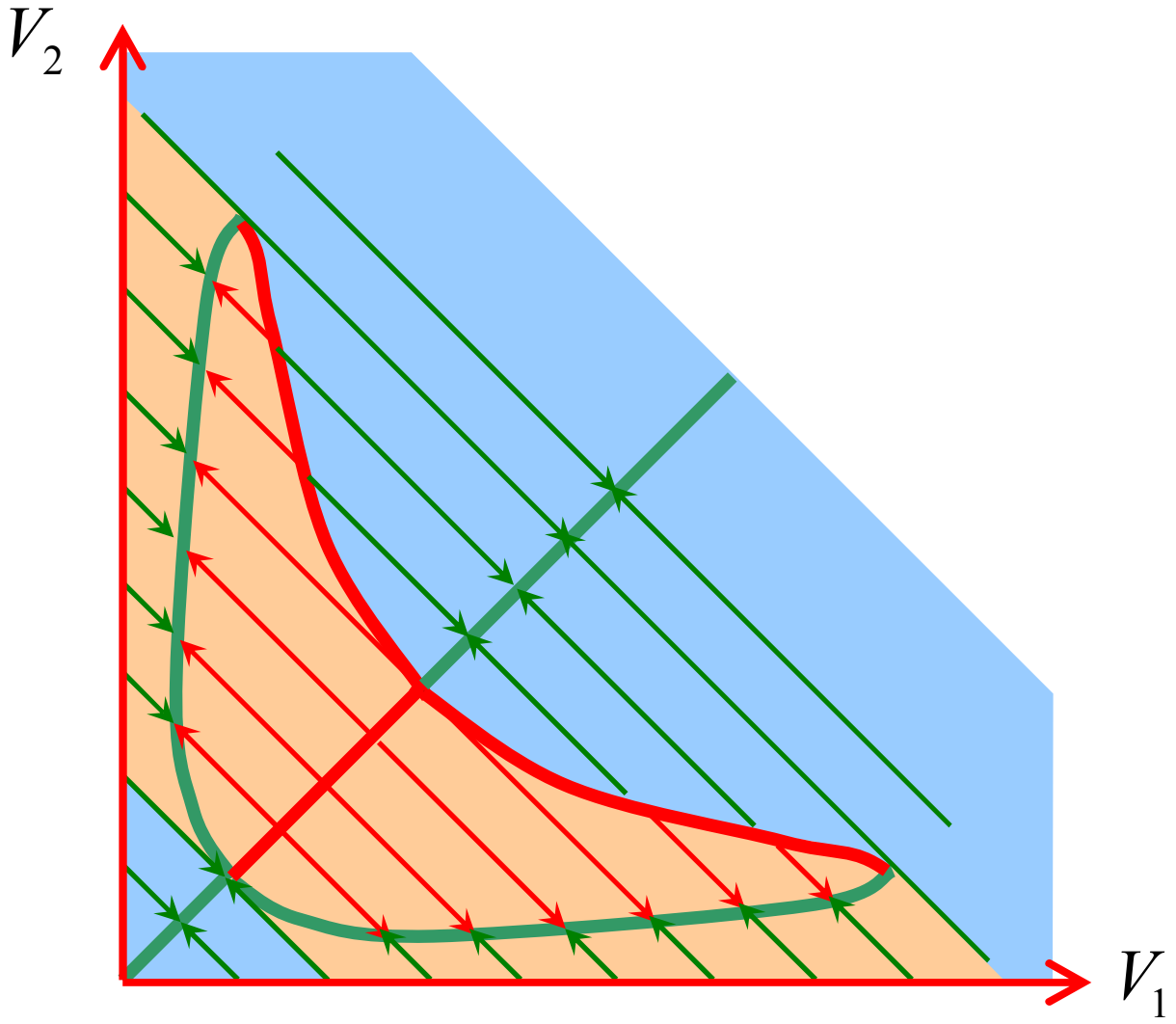


Equilibrium of non-equal volumes

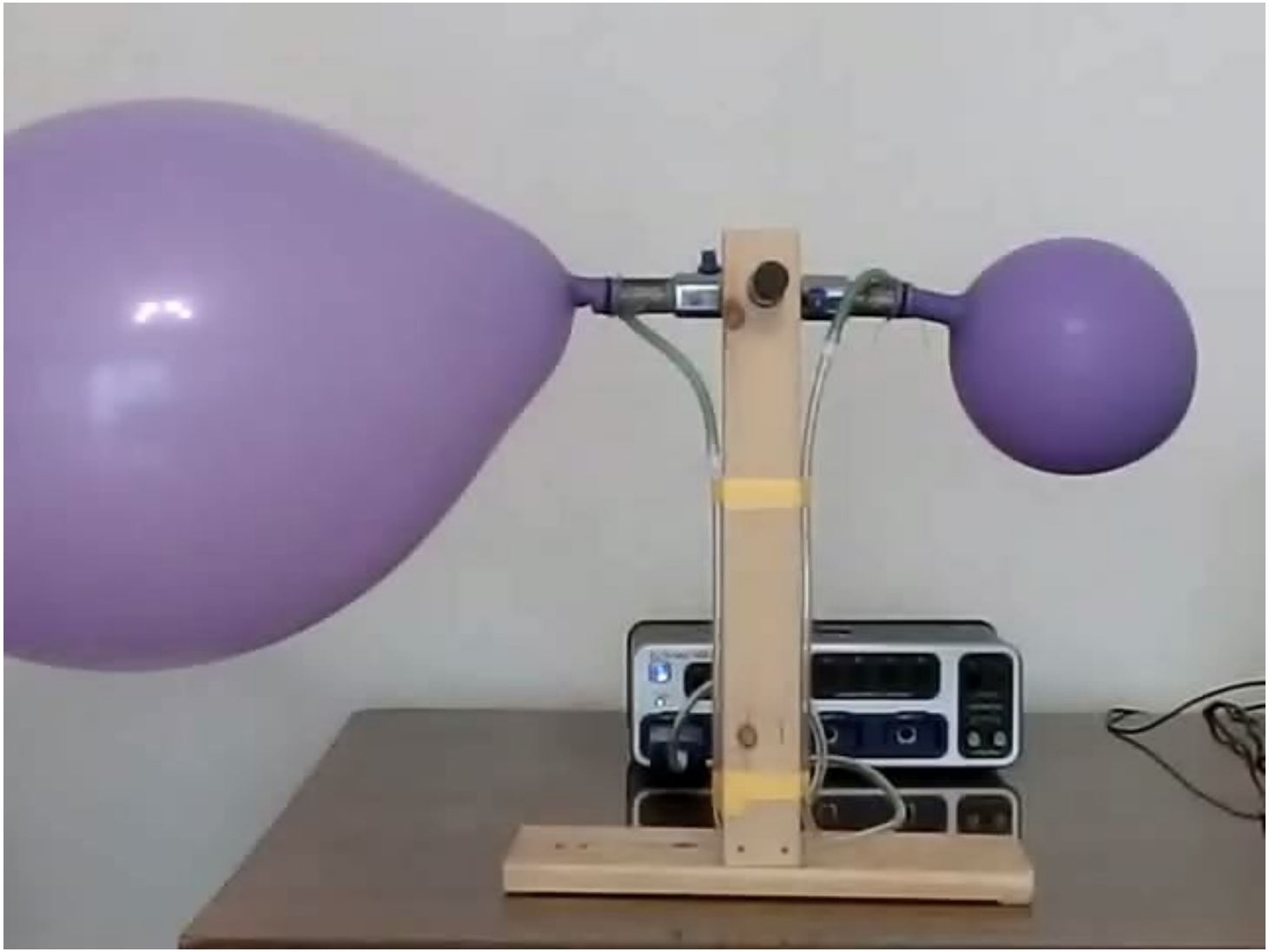




Phase diagram

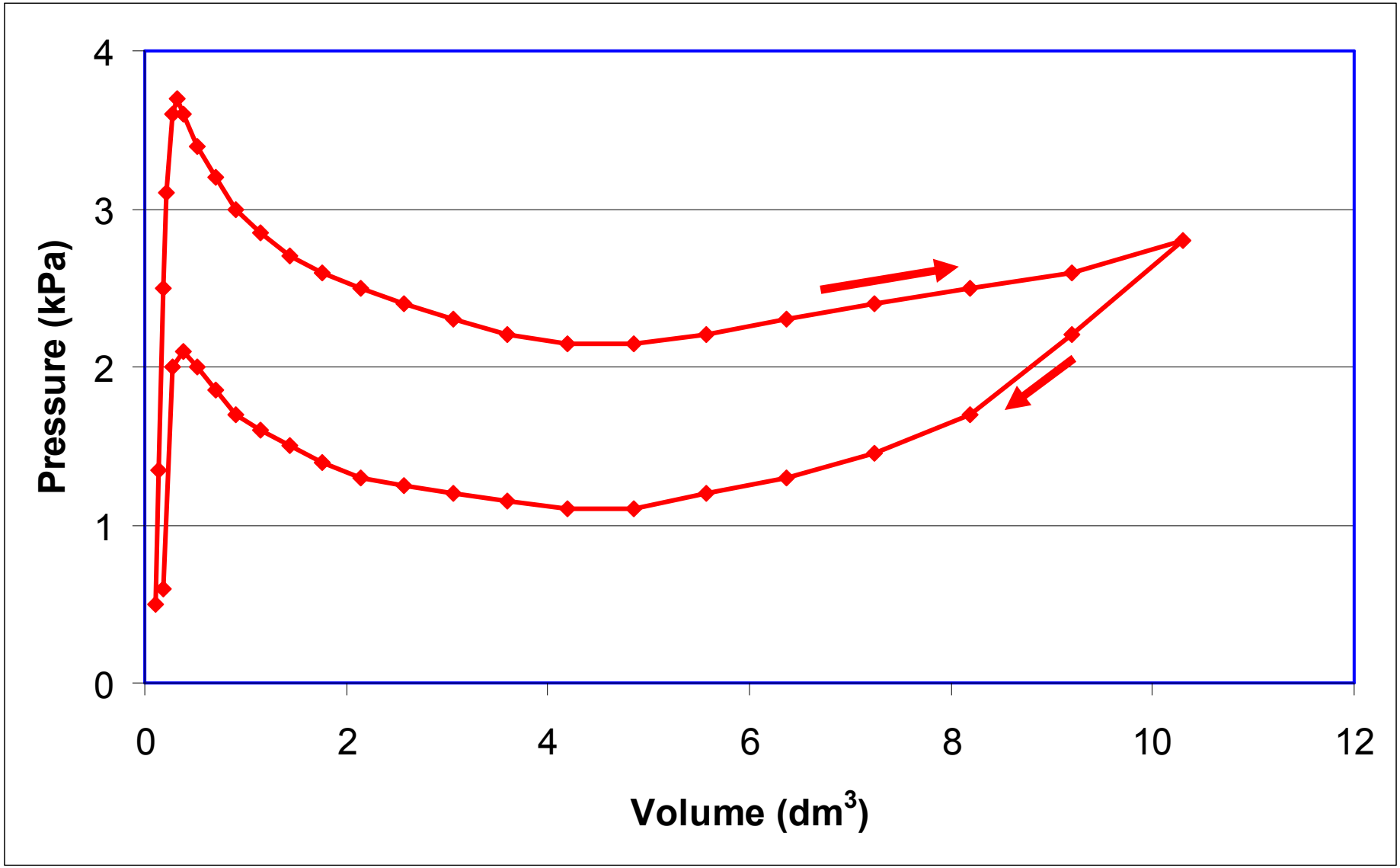


#3: Strange behavior…

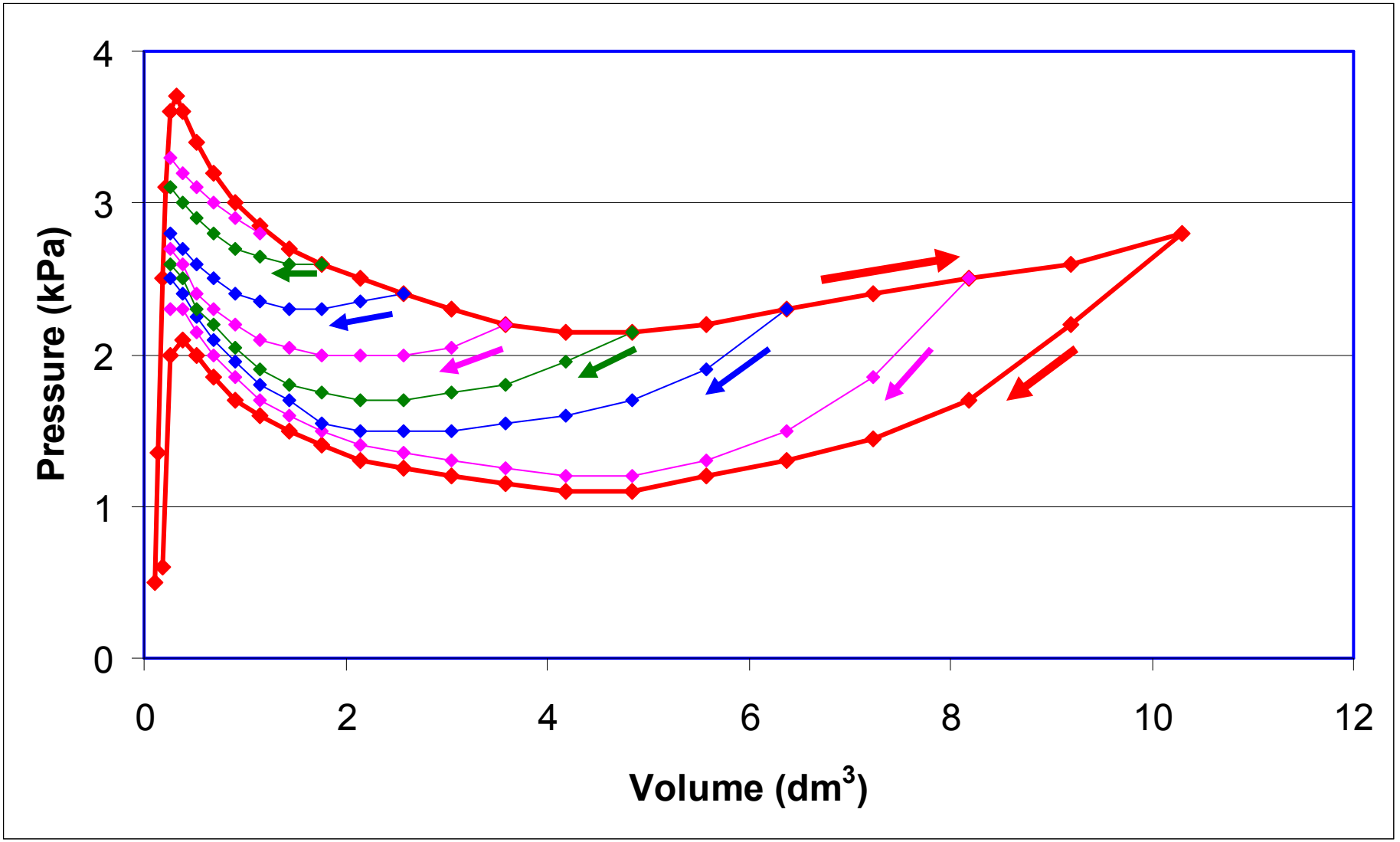


Effect of rubber hysteresis

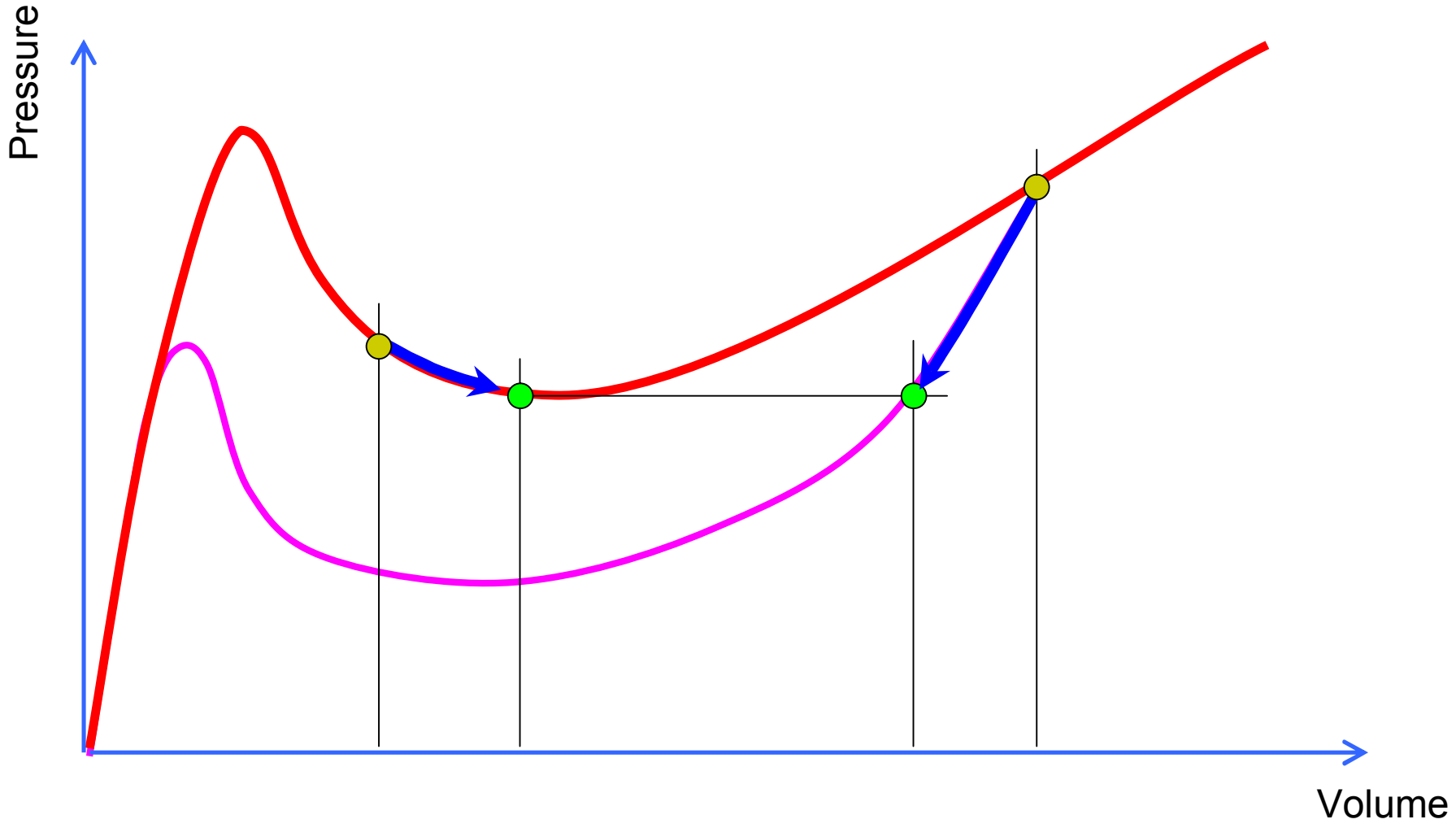
Pressure vs. volume



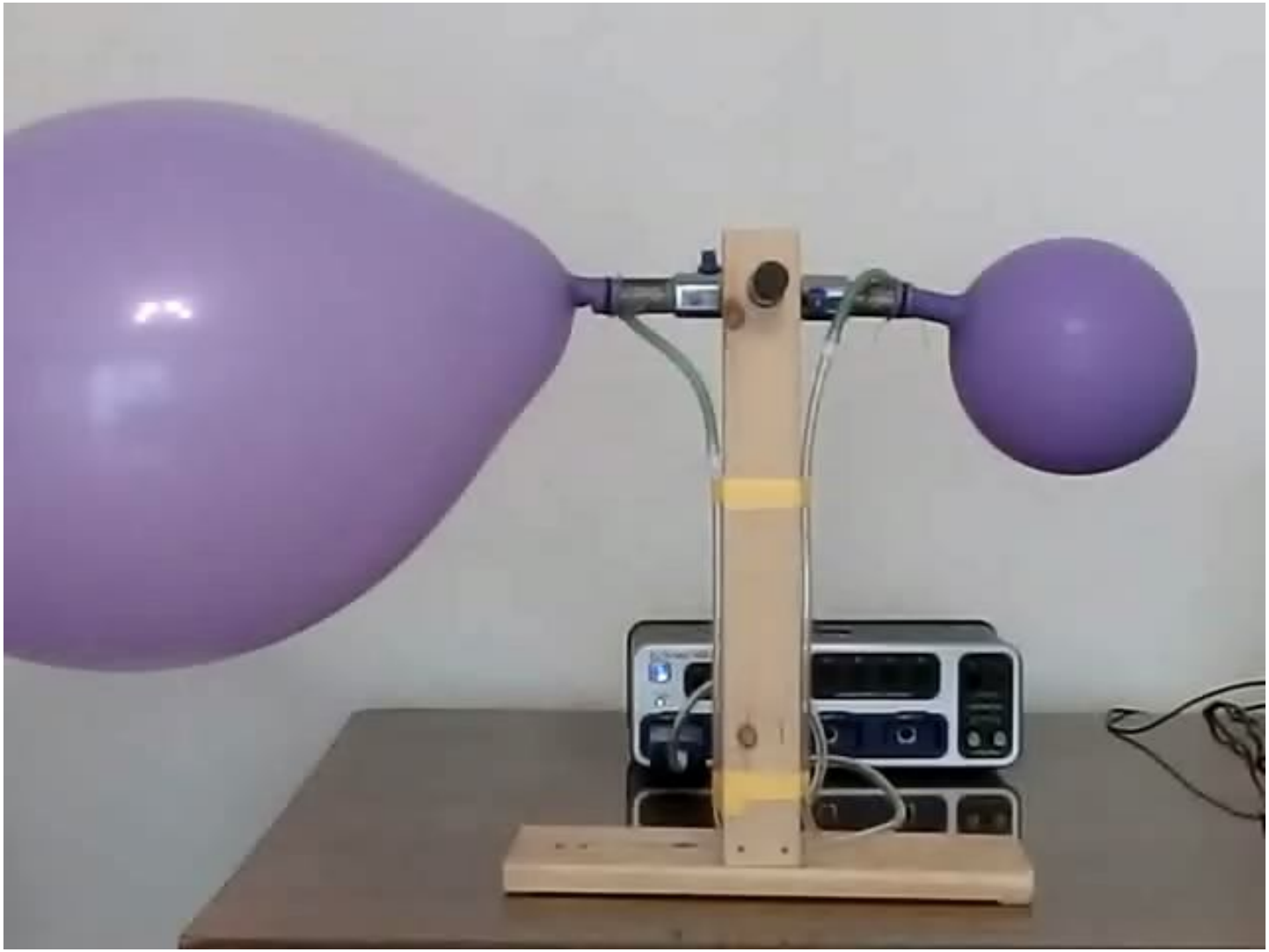
Pressure vs. volume



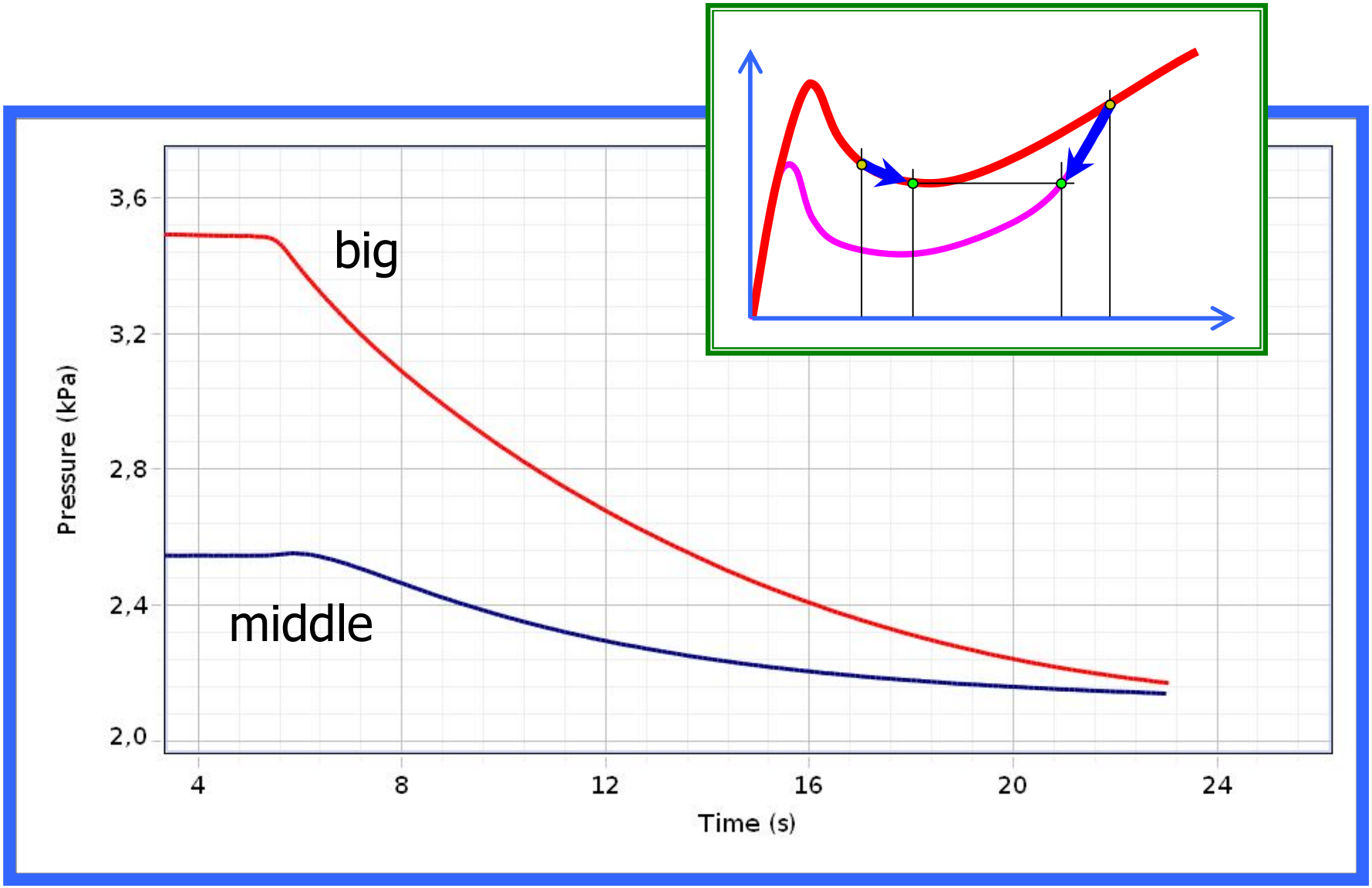
#3: Incomplete volume equalization



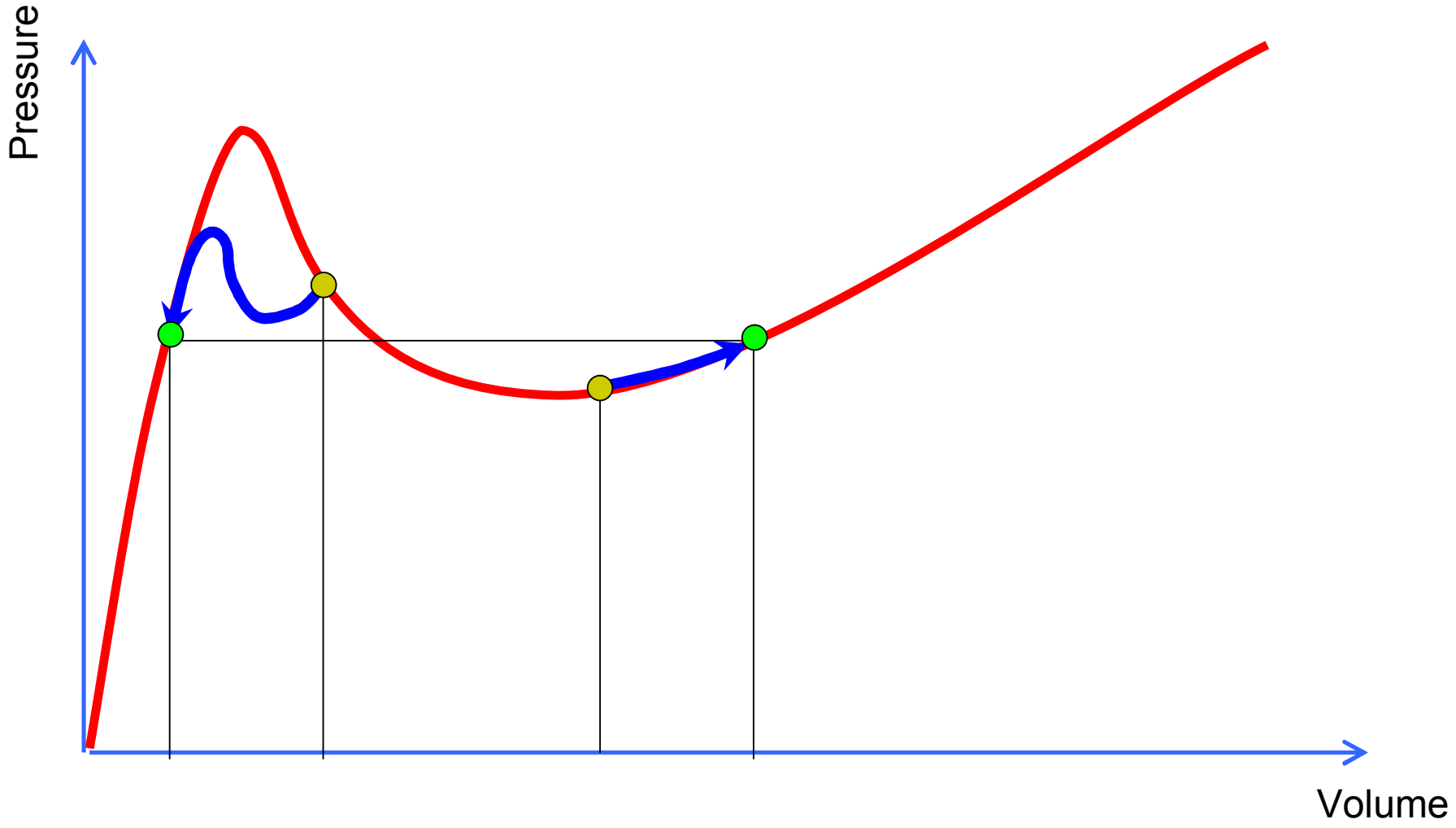
How it happens



Relative pressure graph

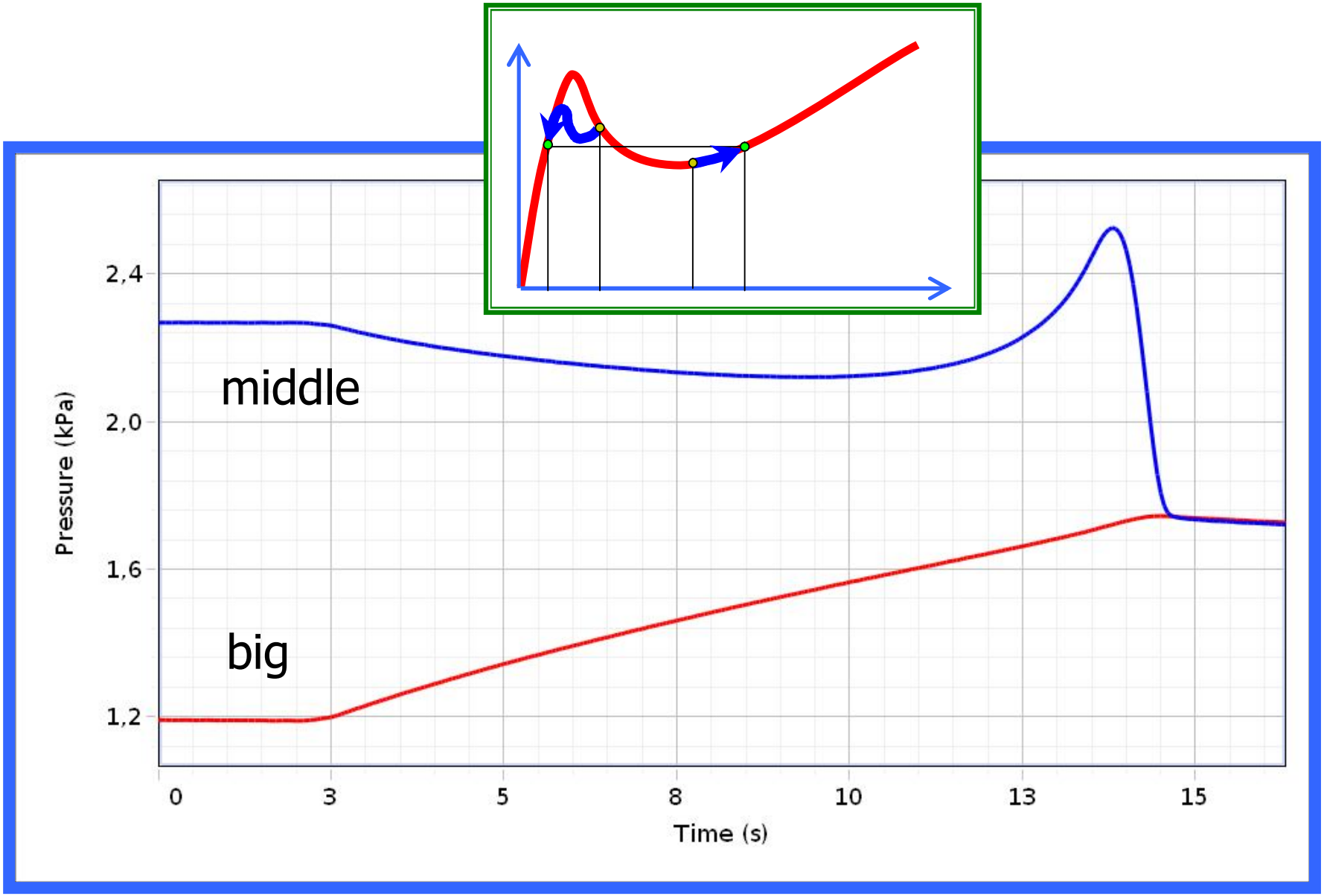


#4: Big is inflated, middle is deflated

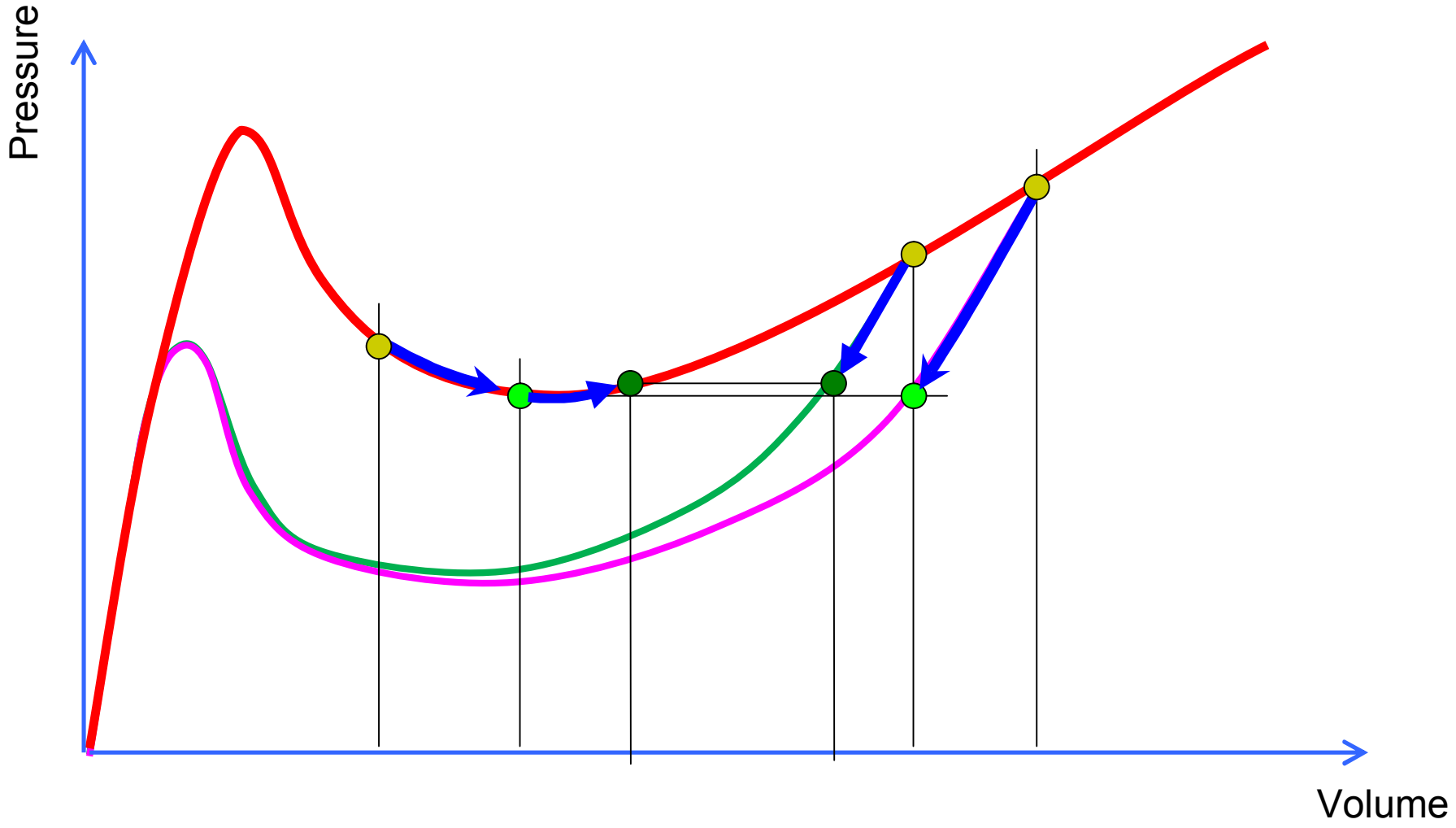


How it happens

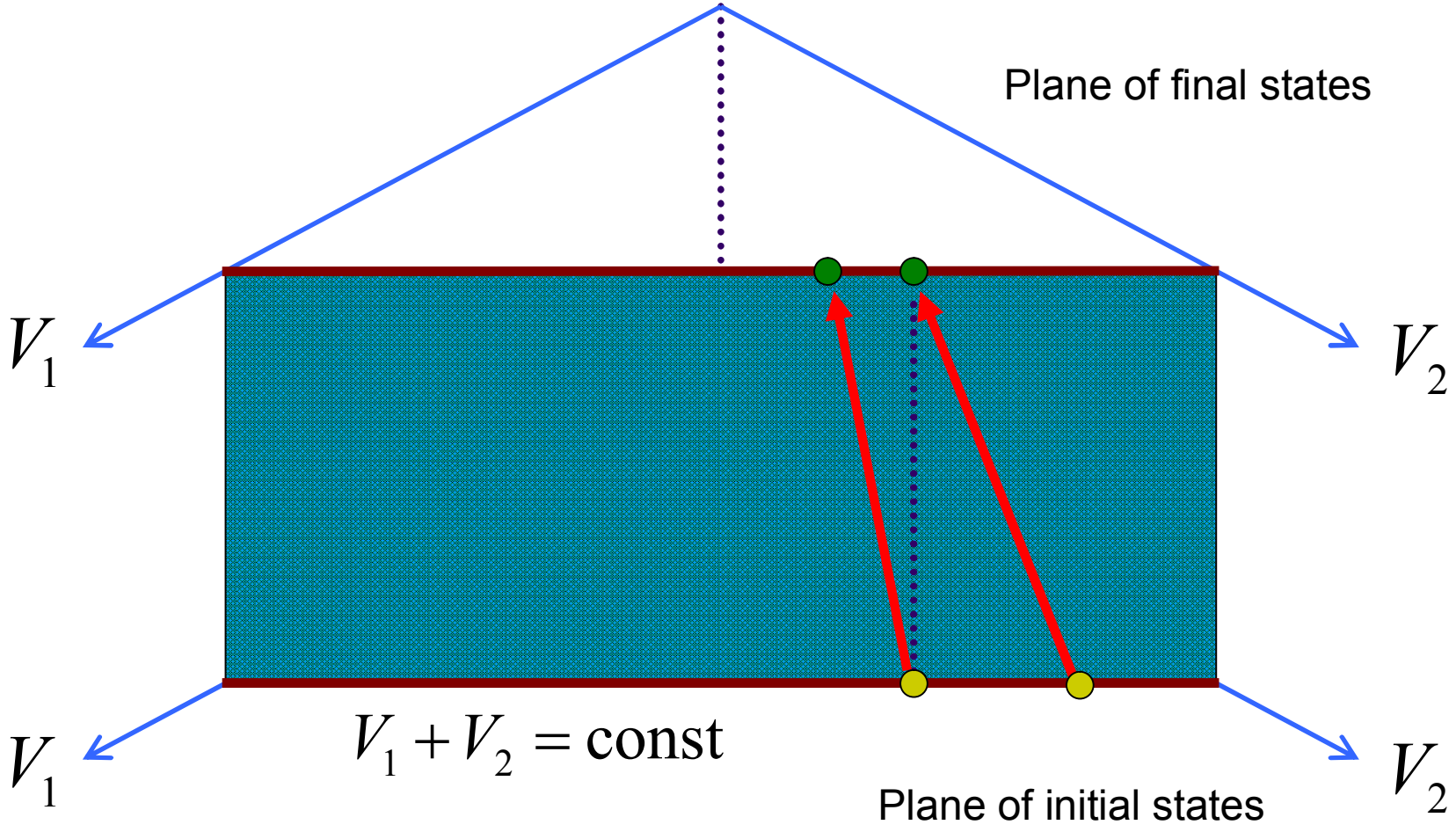
Relative pressure graph



Is the phase diagram valid?

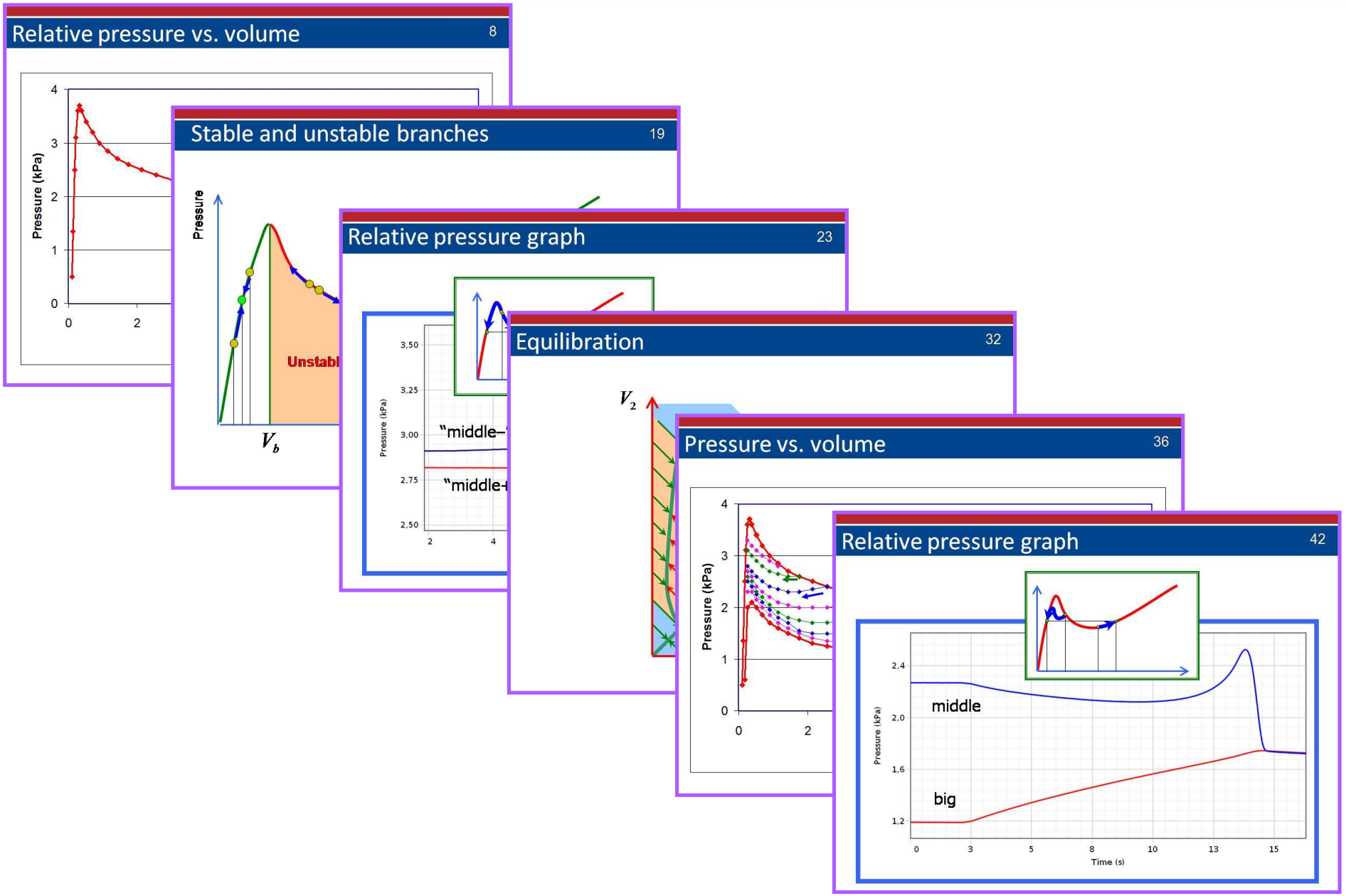


Doubling of the phase plane



Summary

Conclusions



References

- Dreyer W., Müller I., Strehlow P. (1981) “A study of equilibria of interconnected balloons”. *Q. J. Mech. Appl. Math*. **35**, 419–440.

Thank you for your attention!