7. Drawing Pins

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New Zealand
2012

The Problem

- A drawing pin (thumbtack) floating on the surface of water near another floating object is subject to an attractive force. Investigate and explain the phenomenon. Is it possible to achieve a repulsive force by a similar mechanism?

Presentation Structure

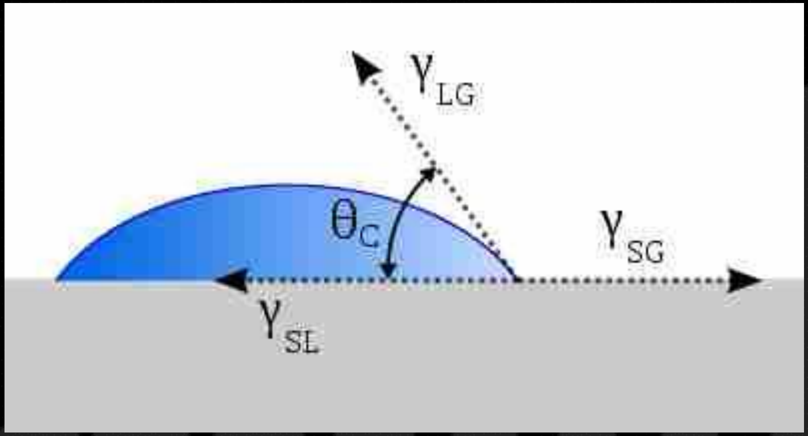
- Definitions/interpretations
- Observations and conditions
- Theory
- Further experimentation
- Conclusion

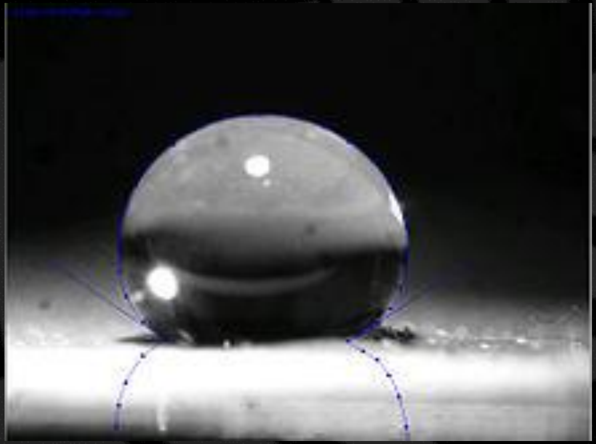
Definitions

- Drawing pin density > water
- Flotation due to surface tension and buoyancy
- **Surface tension** is a property of the surface of a liquid that allows it to resist an external force. In water, it is caused by Hydrogen Bonding of water molecules

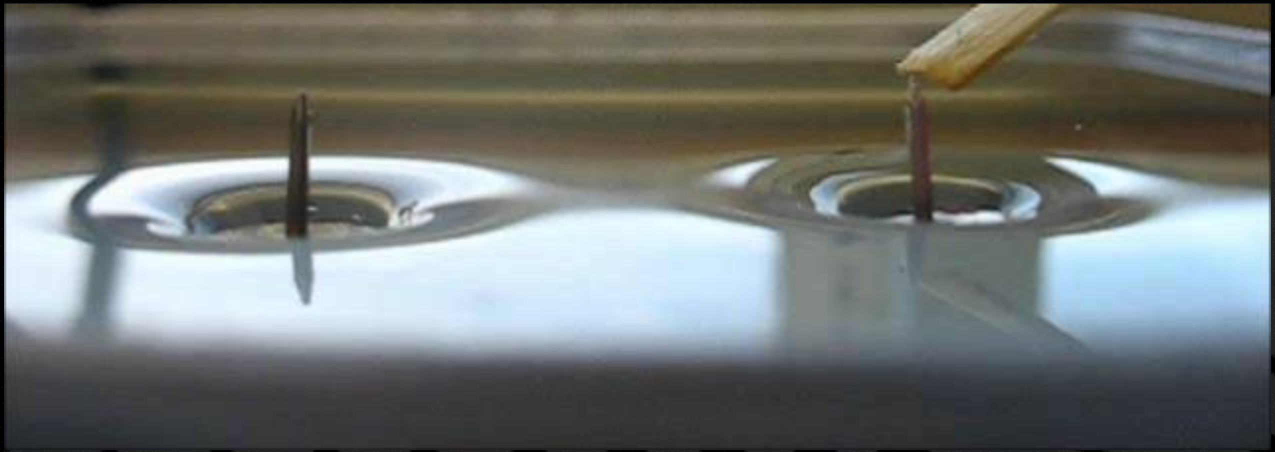
Definitions

- Contact angle
- Wetting & non-wetting
- Hydrophilic & hydrophobic

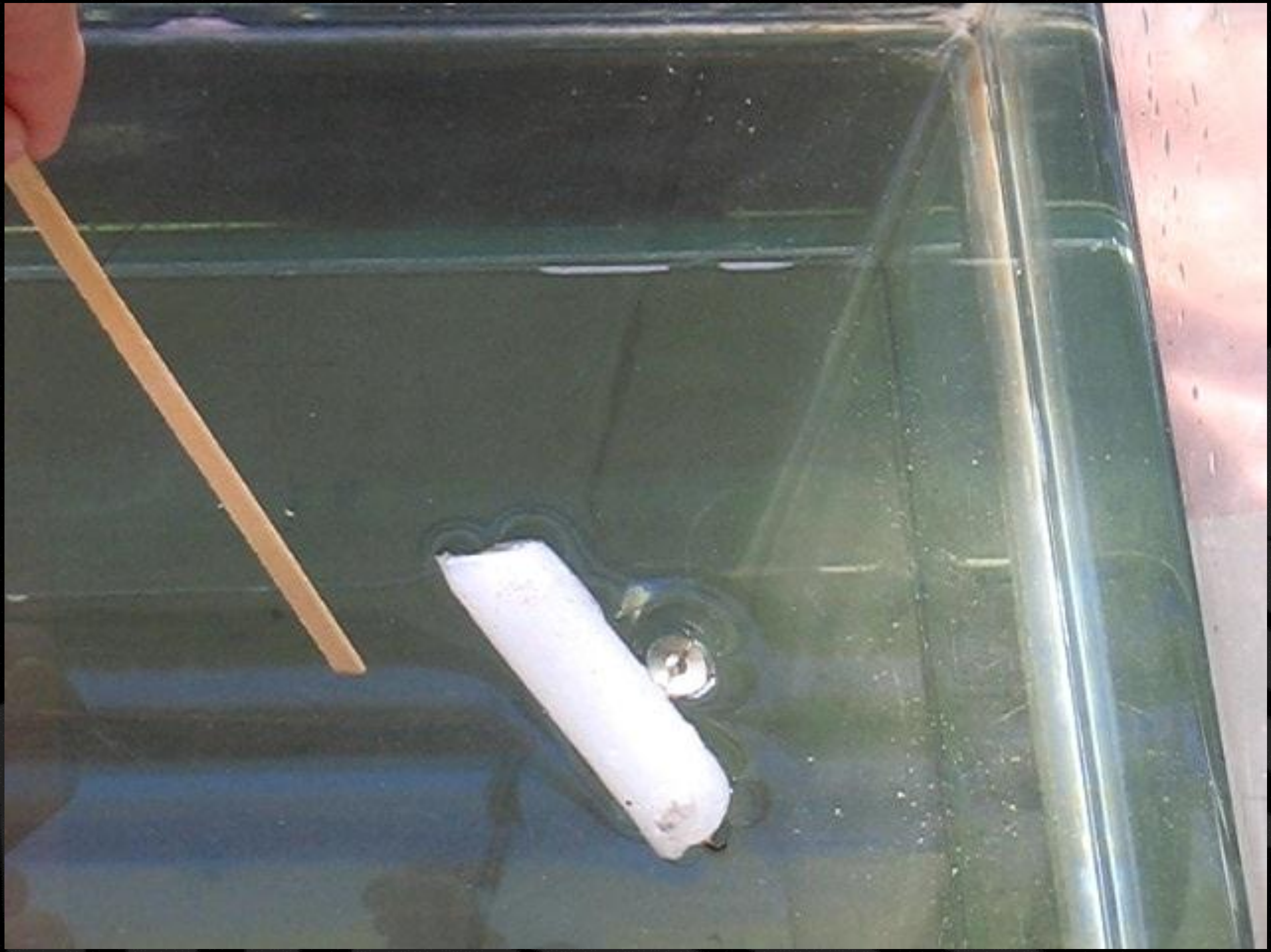




Attraction



Attraction

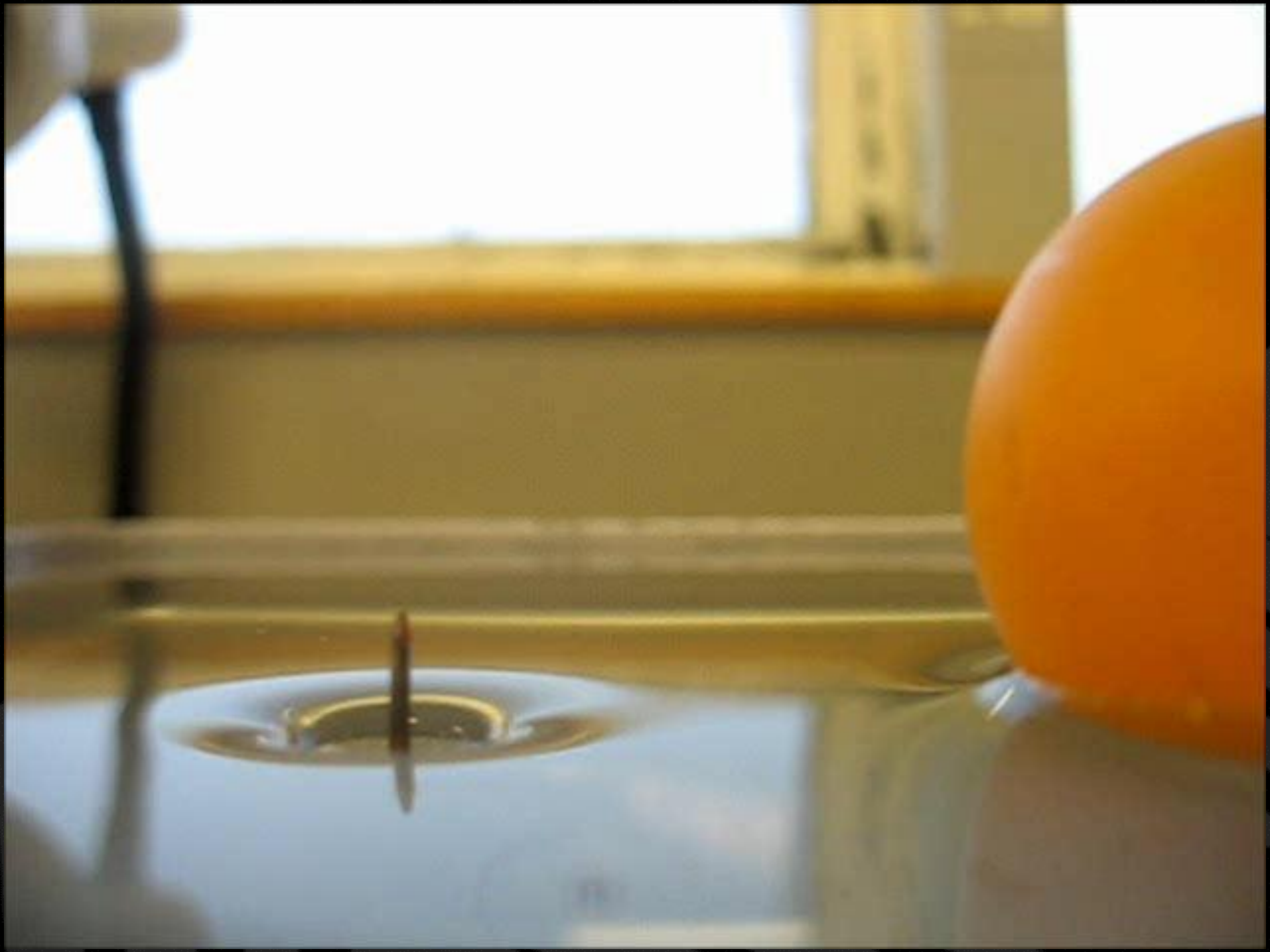


Attraction

Attraction

Attraction

Repulsion



Repulsion

Repulsion

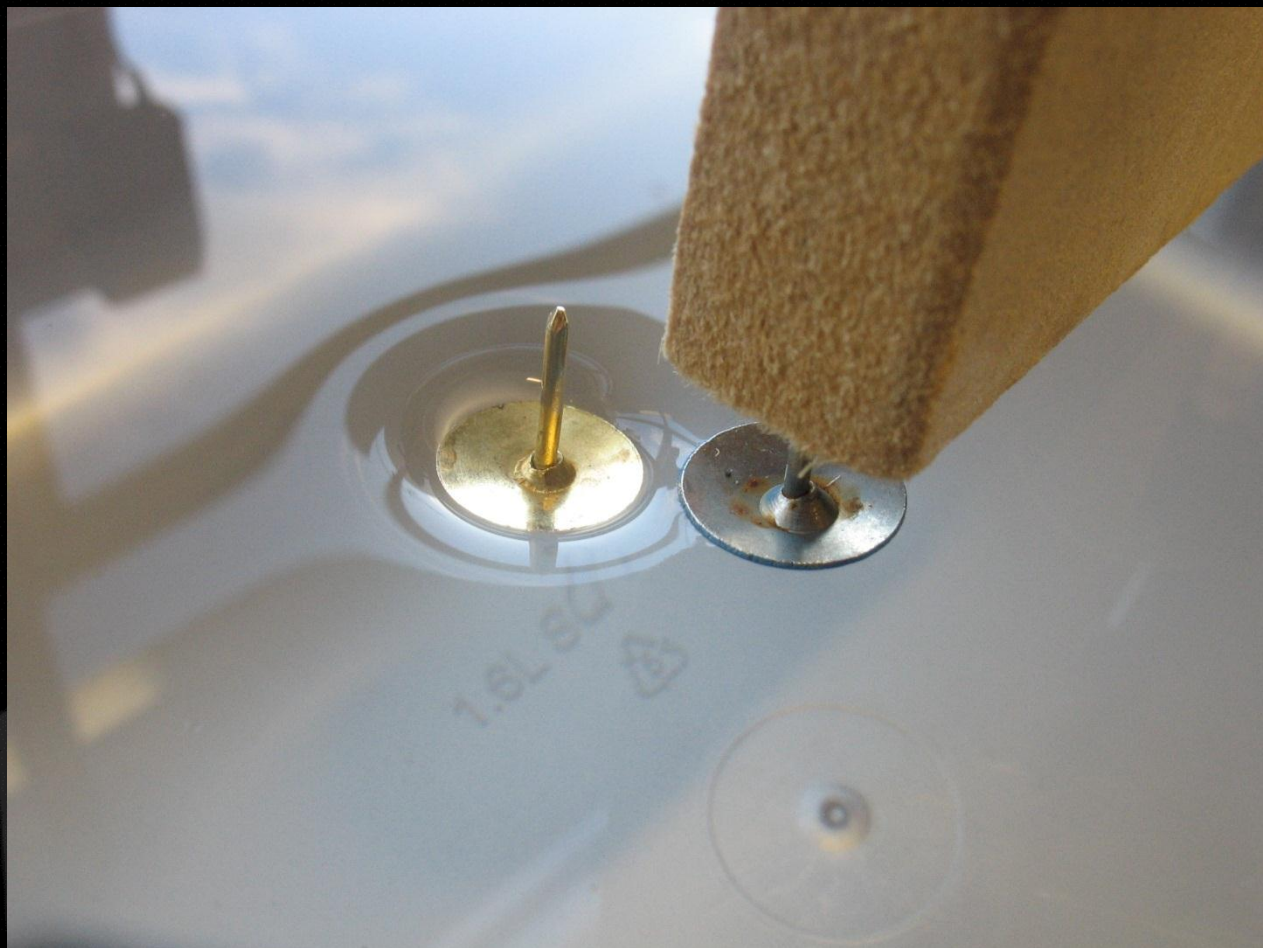
Phenomenon Summary

- Like curves attract; unlike curves repel
- Confirmed with 2 ping pong balls: they attracted

Detergent

Water Control

Equilibrium

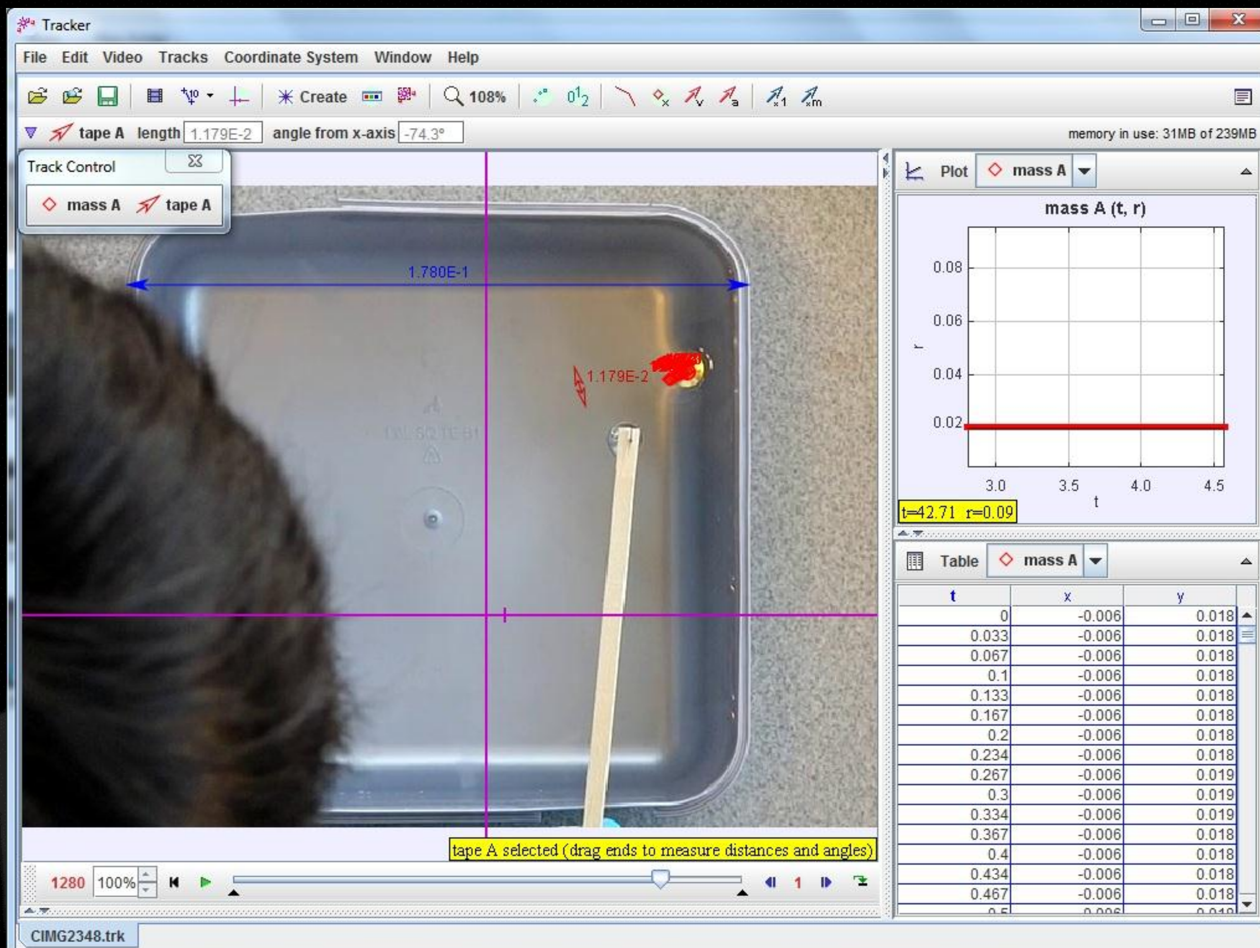


Equilibrium

Theory - Wells

- Interaction of deformations

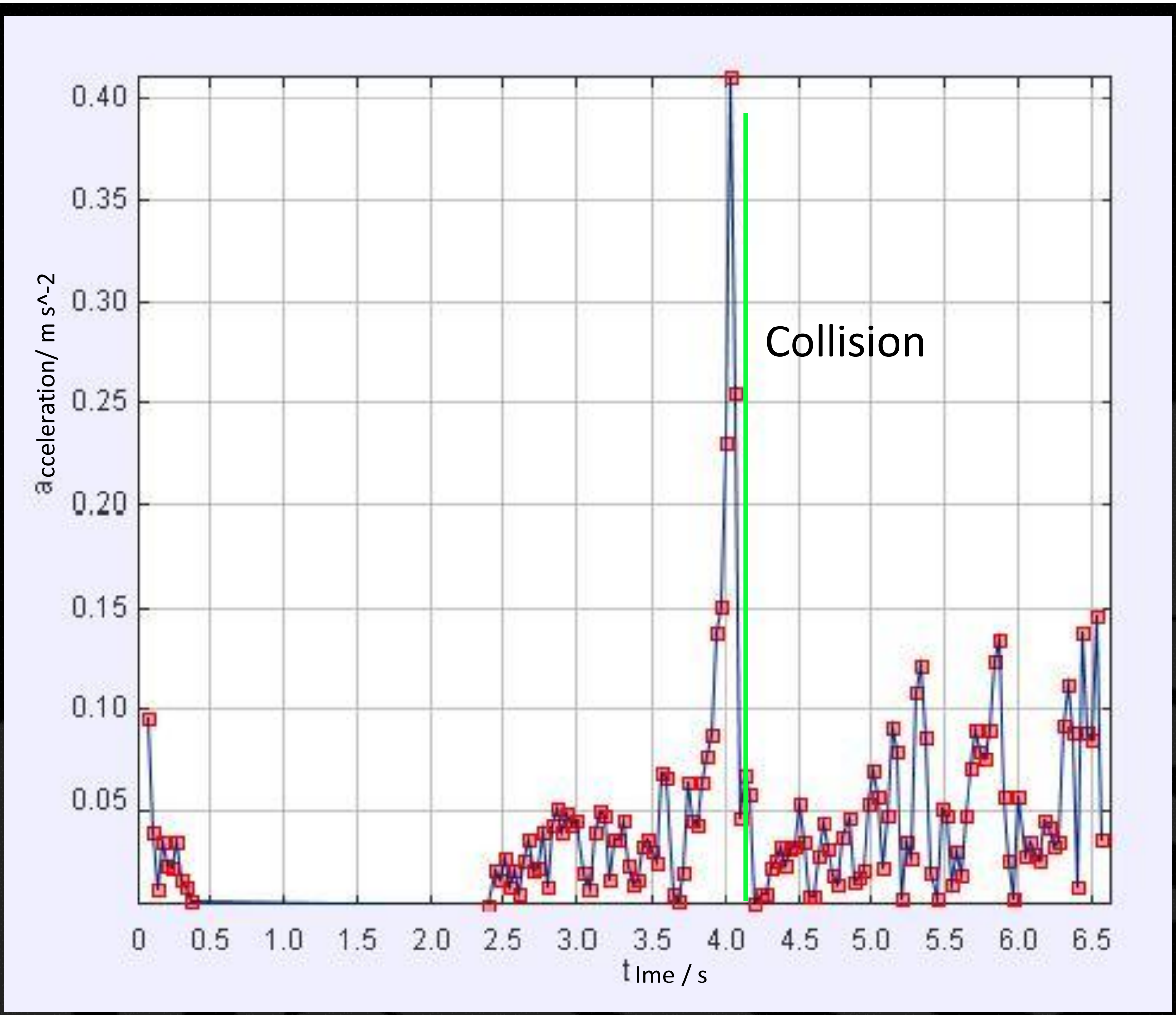
Theory - Wells



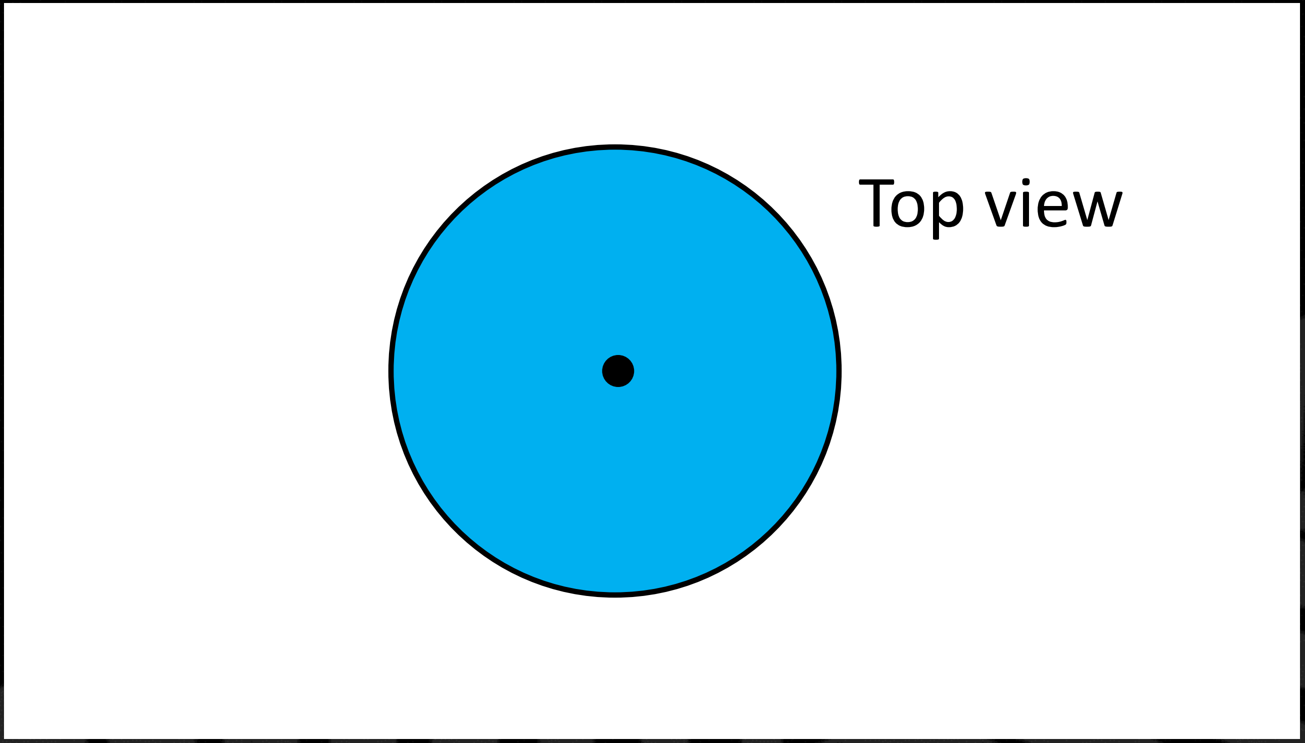
Theory - Wells

- Measurements: calibrated measuring tape in Tracker
- No attraction or repulsion beyond a certain distance: ~13.1 mm
- Well radius of ~12.5 mm

Theory - Wells



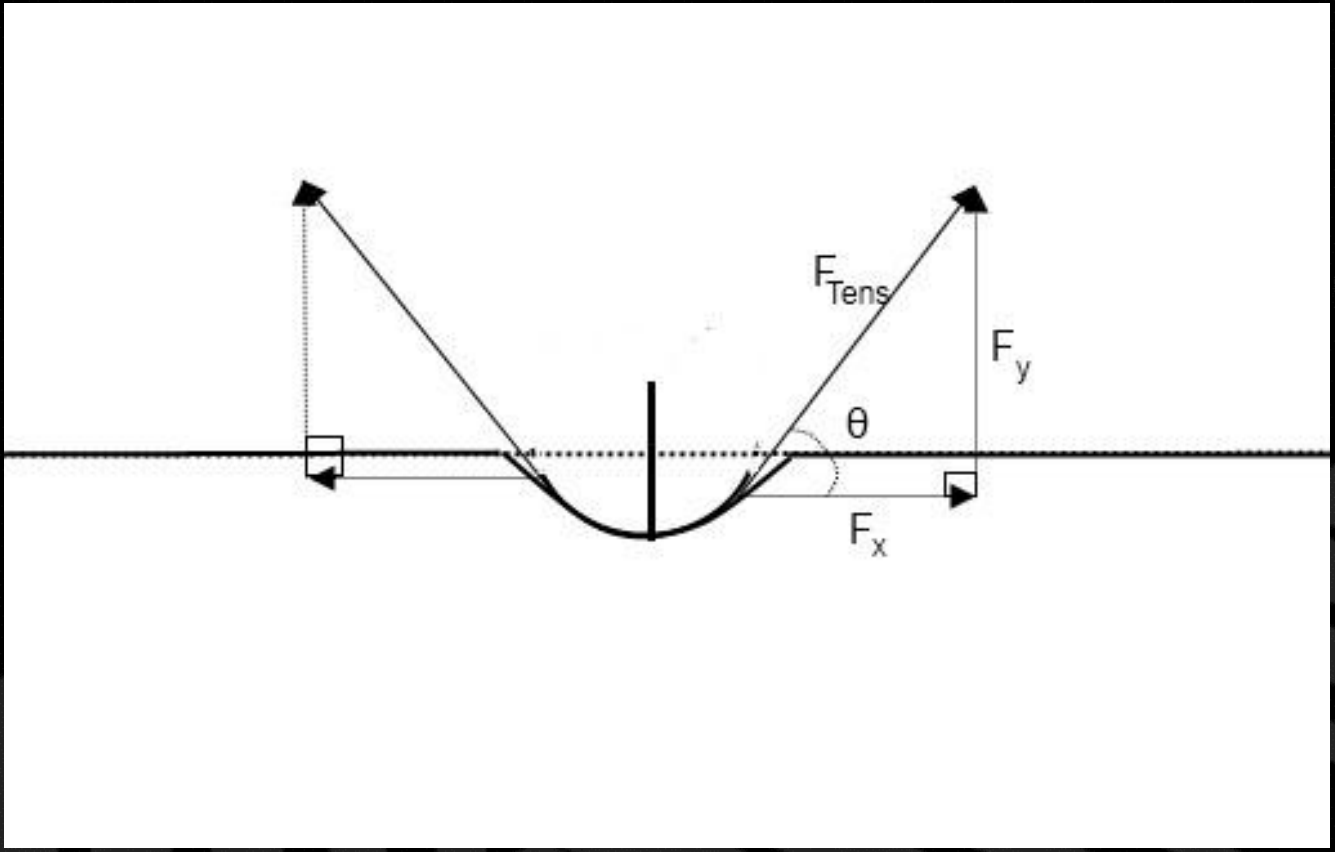
Theory – Surface Tension



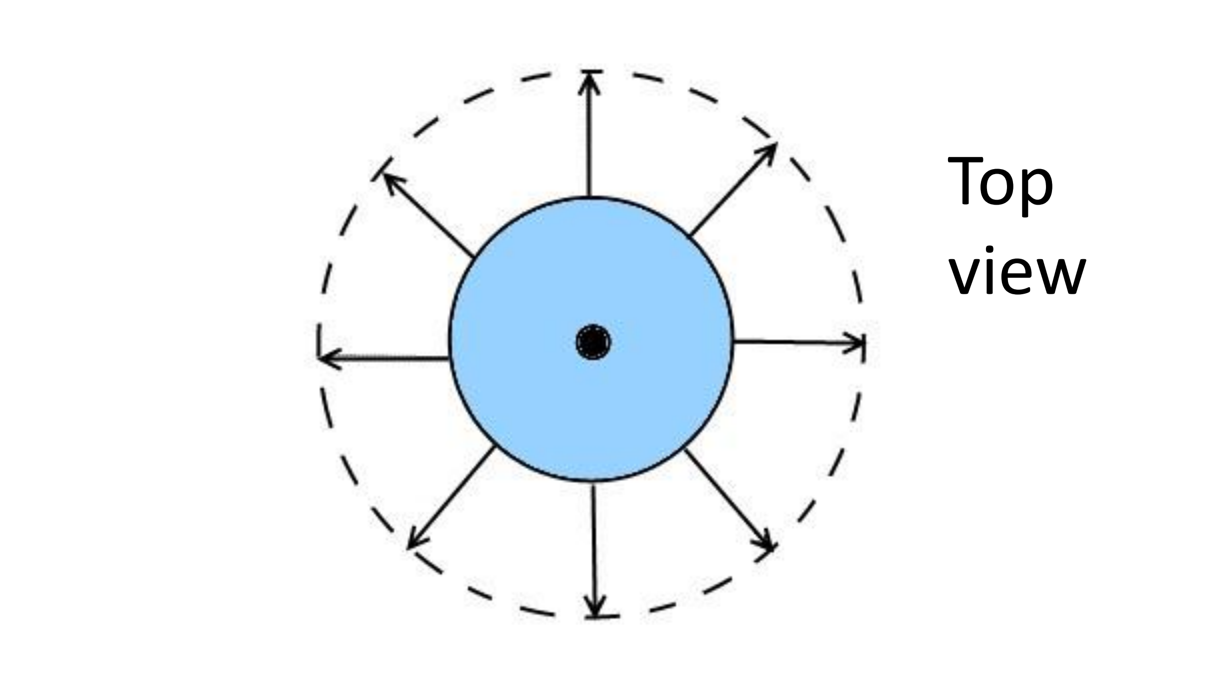
$$\sigma = \frac{F}{l}$$

σ=surface tension l=length=2πr F=force

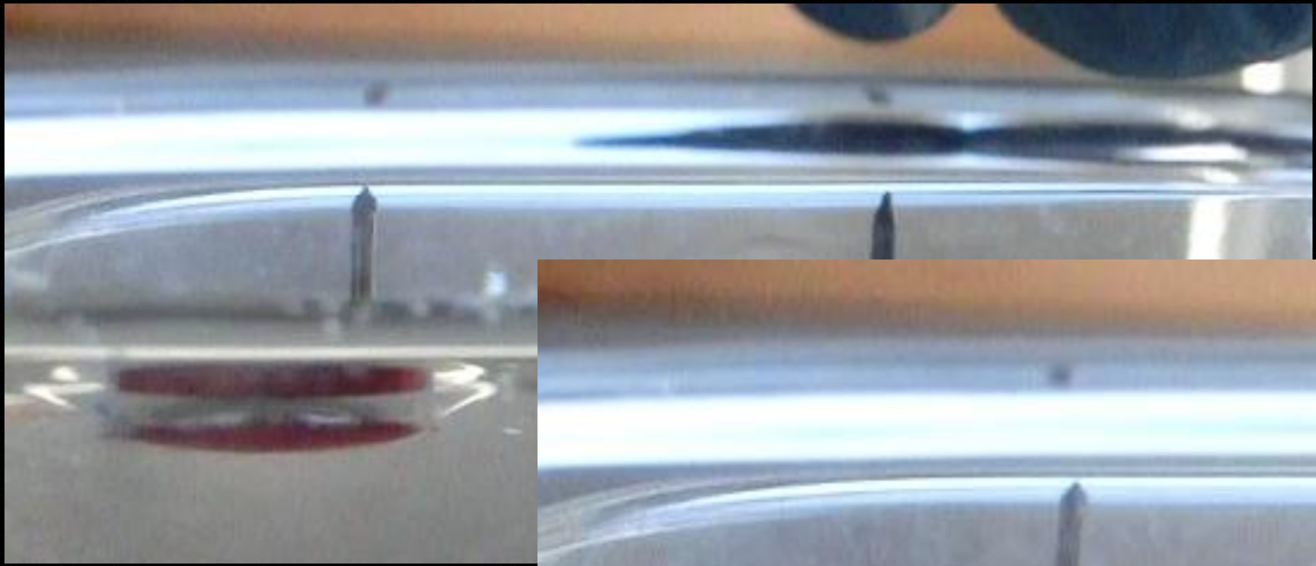
Theory – Surface Tension

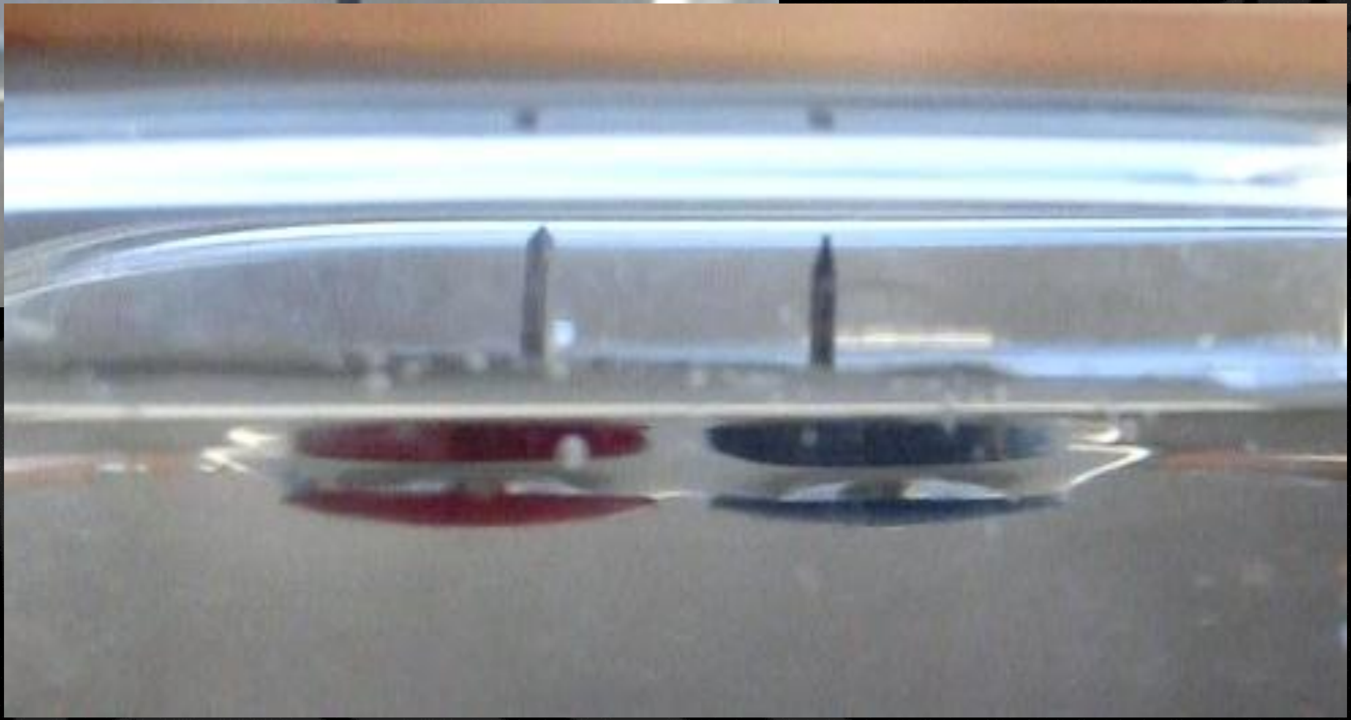


Theory – Surface Tension



Theory – Net Forces





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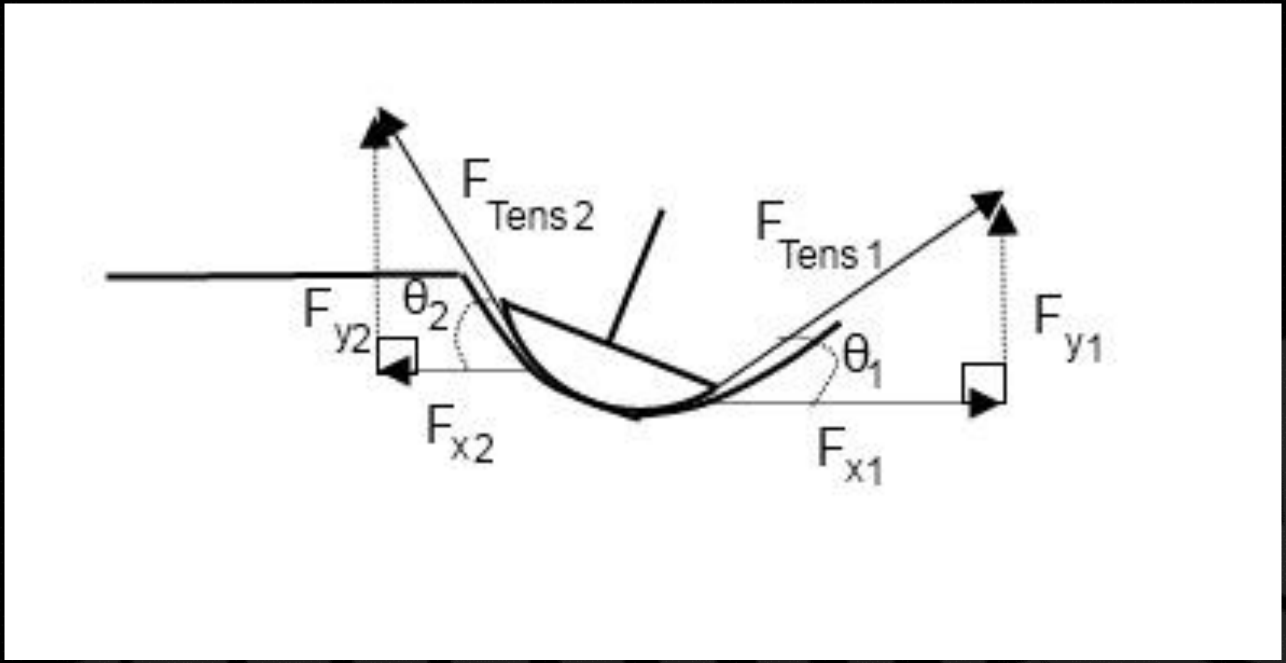
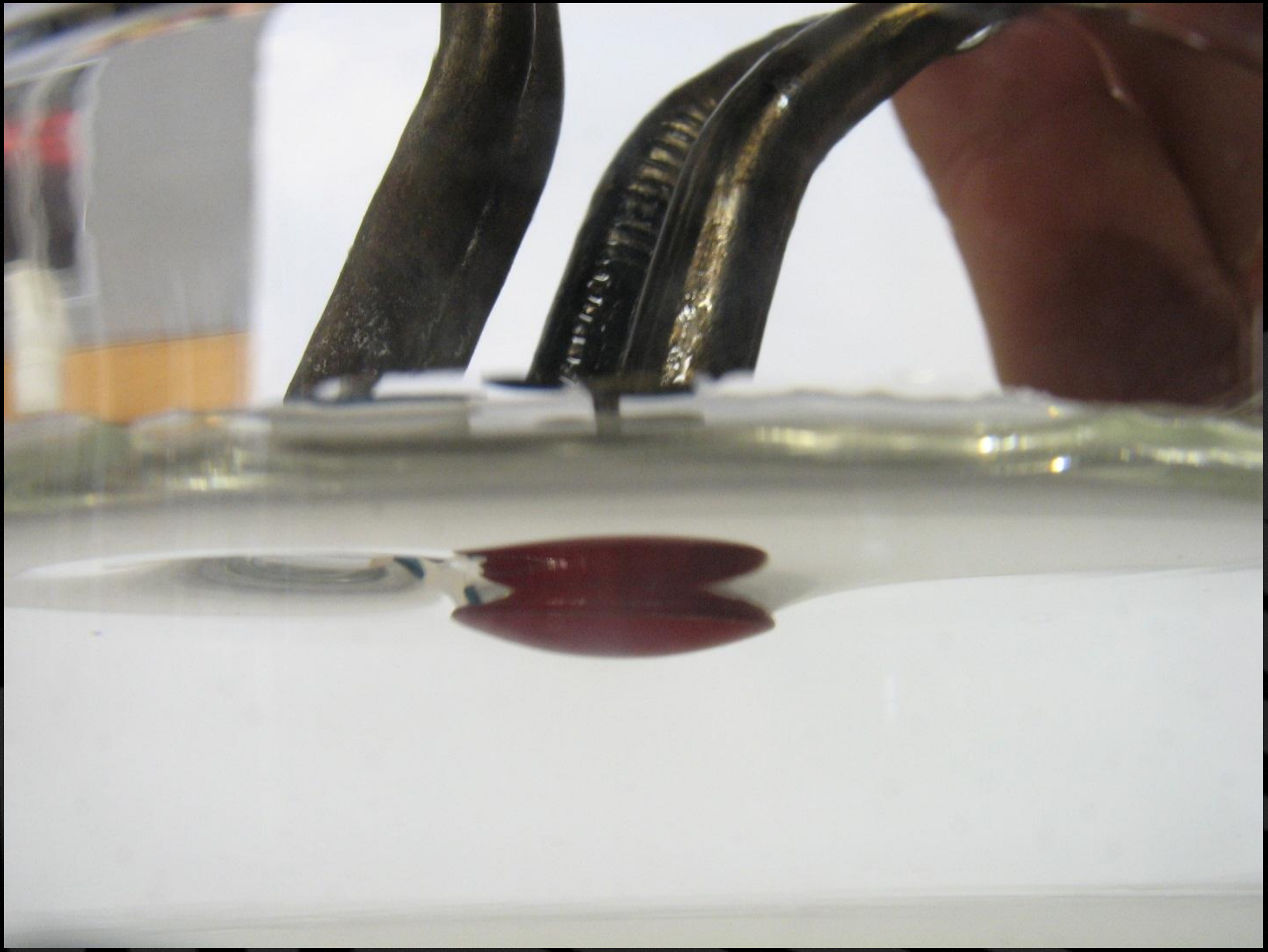


$$F_{Tens\,1} = F_{Tens\,2}$$

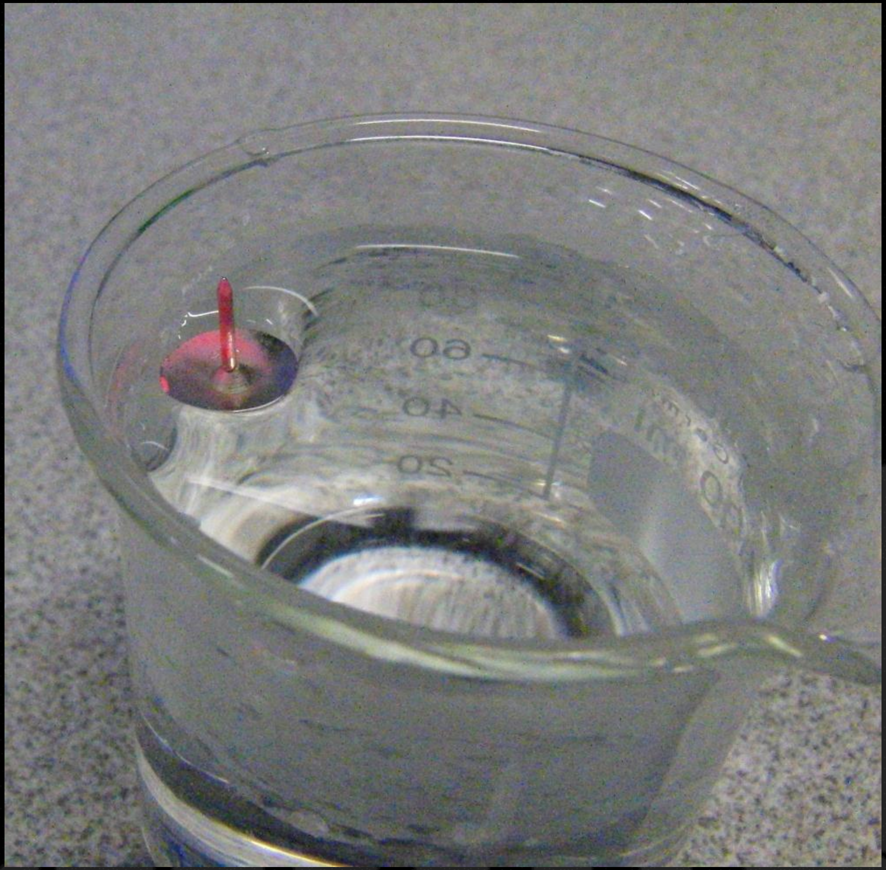
$$F_{x1} > F_{x2}$$

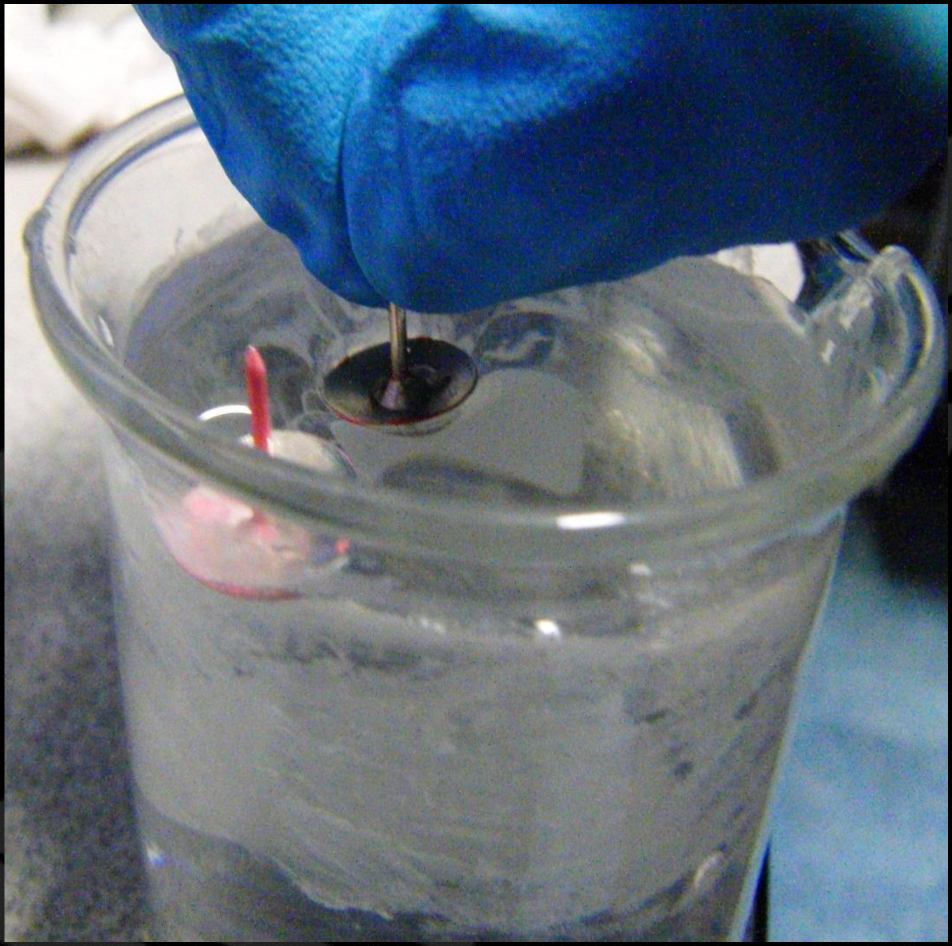
Net force $\longrightarrow$

Theory – Net Forces



Changing the Phenomenon





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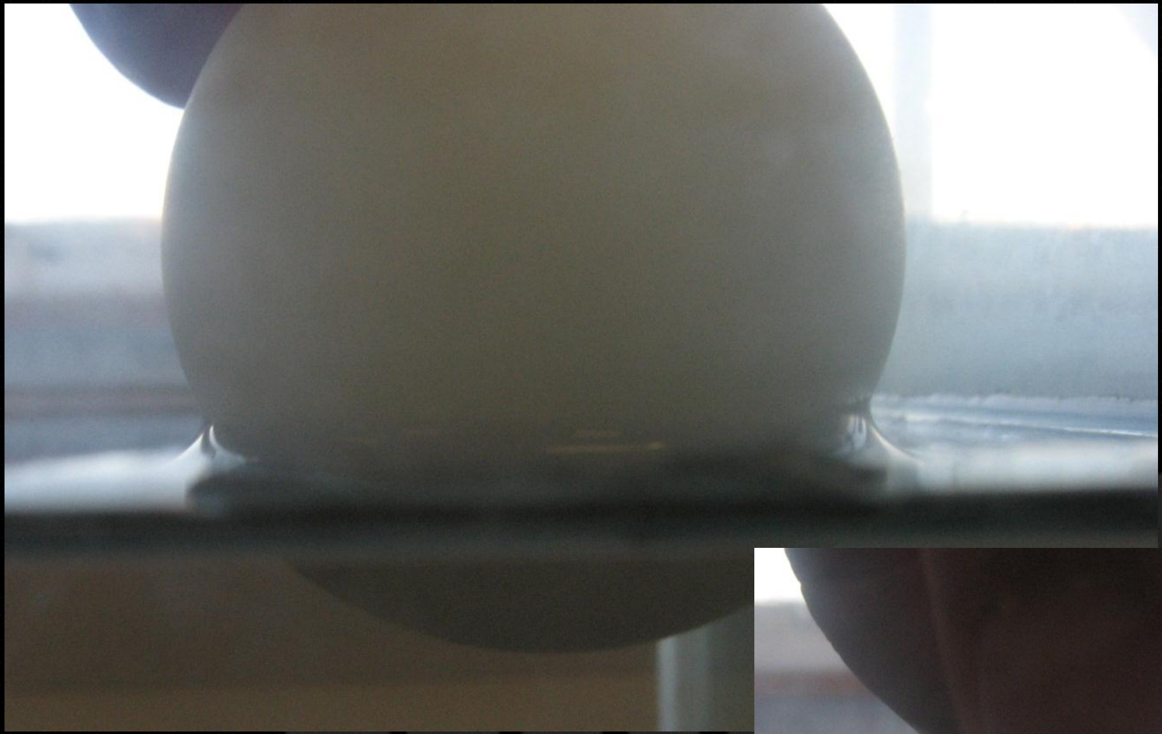
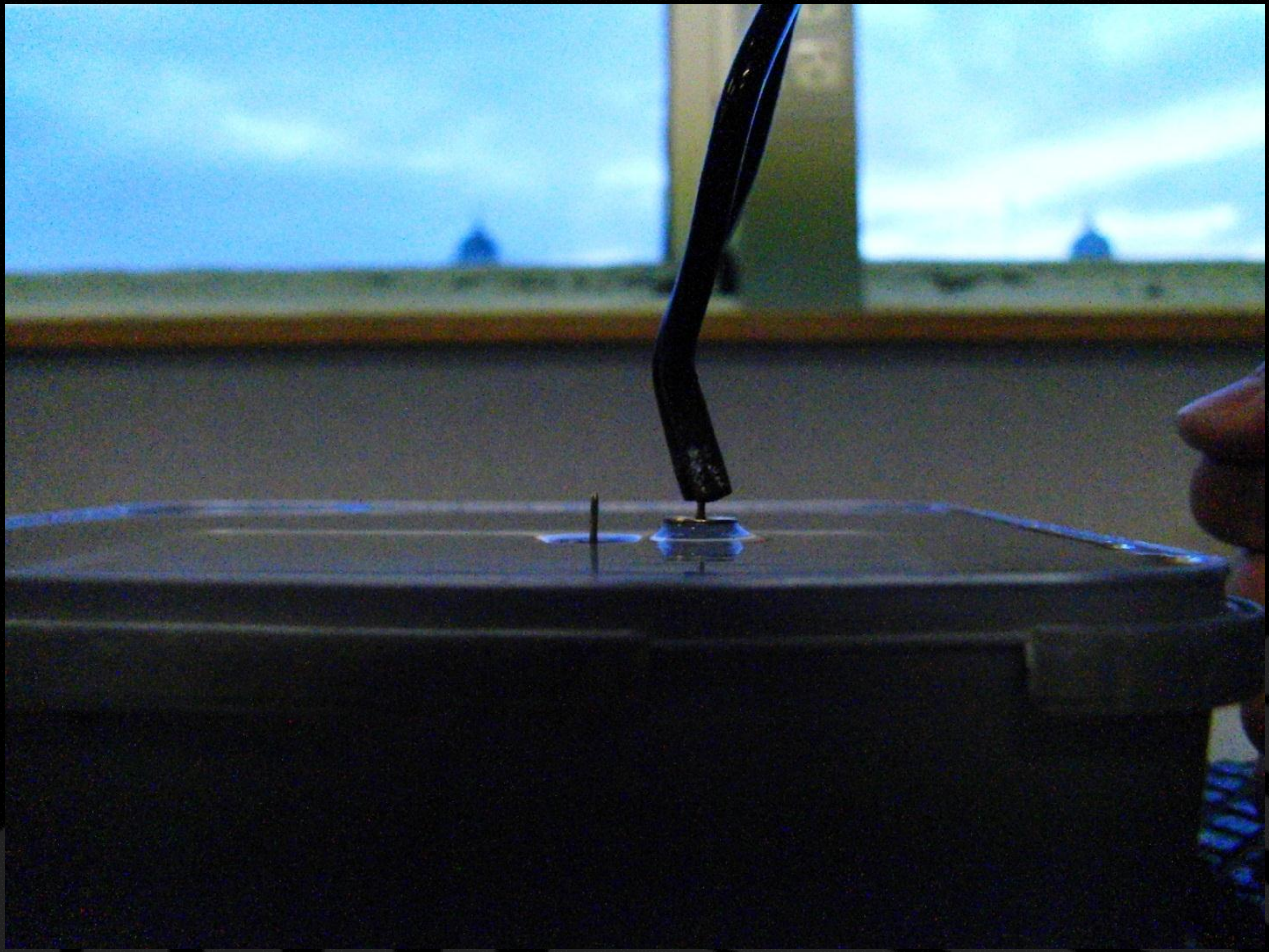


Changing the Phenomenon



- A finger, a candle, folded tinfoil – they all work
- Hysteresis

The Problem

- A drawing pin (thumbtack) floating on the surface of water near another floating object is subject to an attractive force. Investigate and explain the phenomenon. Is it possible to achieve a repulsive force by a similar mechanism?

Conclusion

- All objects deform the surface of the water
- Like curves attract; opposite curves repel
- Lifting and depressing the 2nd object can change the effect from attraction to repulsion
- Material and buoyancy matter only so far as they dictate the nature of the curve – any object will produce one or the other effect
- When the 2nd object has a very small deformation, there exists an optimum distance at which the floating pin is most stable
- The accelerating forces are caused by surface tension

Thank you for listening

References

- **An Introduction to Fluid Dynamics. By** G.K. Batchelor. Cambridge University Press, 1967
- **Introduction to Interfaces and Colloids.** By J.C. Berg. World Scientific Publishing Co., 2010
- College Physics. By R.A. Serway, J.S. Faughan, C. Vaille. Cengage Learning, 2012.
- http://www.oup.com/uk/orc/bin/9780199571185/9780199571185_ch02.pdf
- http://www.cns.gatech.edu/~predrag/courses/PHYS-4421-10/Lautrup/surface.pdf
- Professor T.R. Akylas **http://web.mit.edu/1.63/www/Lec-notes/Surfacetension/Lecture3.pdf**

Temperature

- Temperature dependence: goes down from 72mN/m to 68mN/m from 25C to 50C

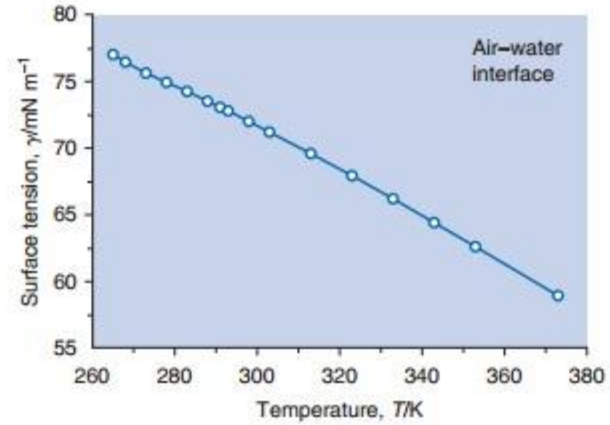


Fig. 2.21 The surface tension of the air–water interface as a function of temperature. (Data from Vargaftik *et al.*, 1983).

Balance of Forces

- Buoyancy force = Vρg

=$(0.01048 \div 2)^2\pi \times 0.0027 \times 1000 \times 9.81 = 0.00187N = 2.28 \times 10^{-3}N$

- Weight force = mg

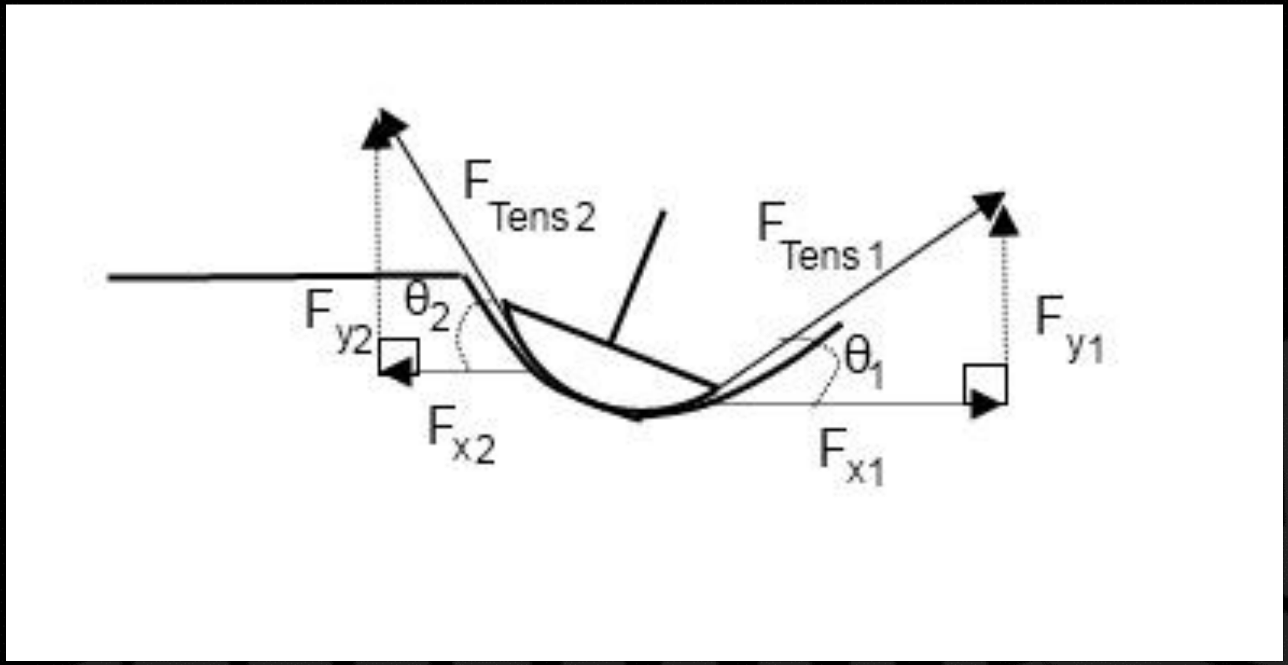
=$0.45\times 10^{-3} \times 9.81 = 4.41 \times 10^{-3}N$

- S.T. Component = $4.41 - 2.28 = 2.13\ mN$

Force Calculations

- $F = \sigma l$
- Fx=0.434 mN
- F=$72.8\times 10^{-3} \times \pi \times 0.0105 = 2.40 \times 10^{-3}$N
- F=ma
- F=$0.46\times 10^{-3} \times 0.40 = 0.18 \times 10^{-3}$N
- $0.18\div 0.434 = 0.42 = 42\%$

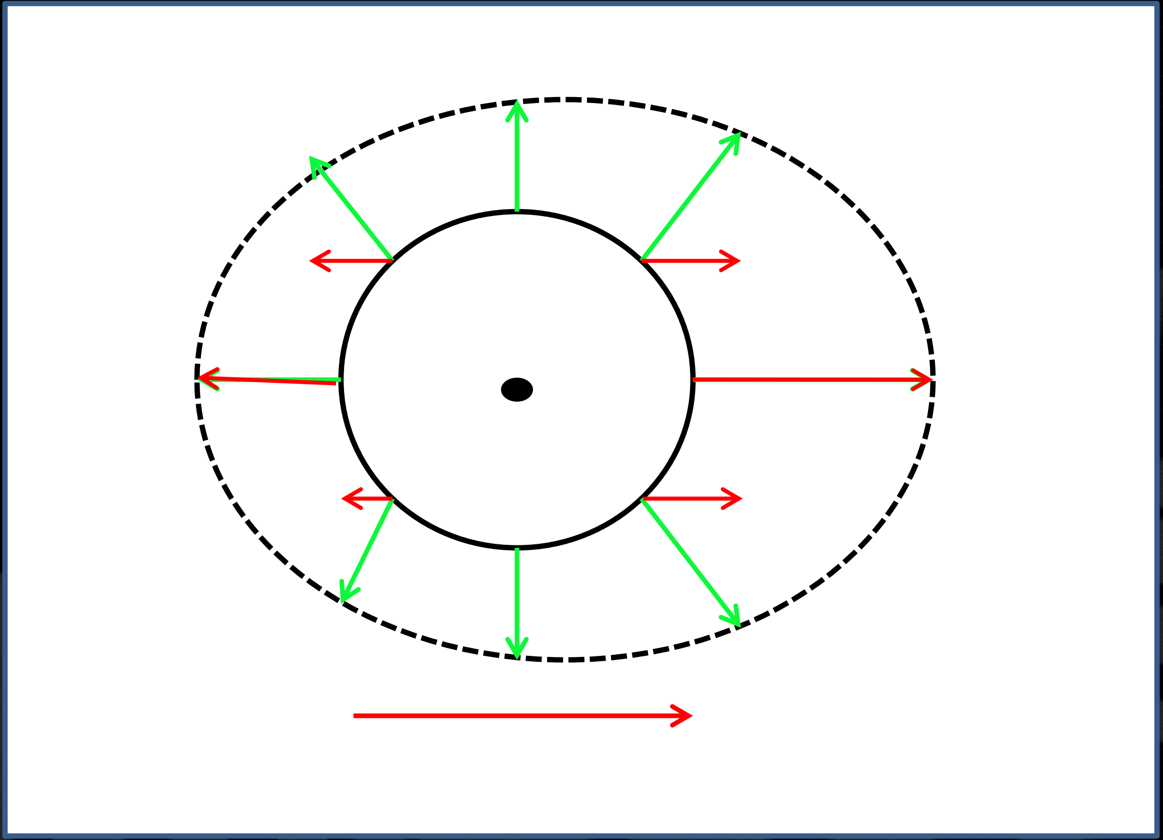
Verification



$$F_{Tens\ 1} = F_{Tens\ 2}$$

$$F_{x1} > F_{x2}$$

Net force



Verification

- Took measurements of the gradient of the curve by laser reflection
- Made 3D model of the well
- well_interaction3D Latest.cdf

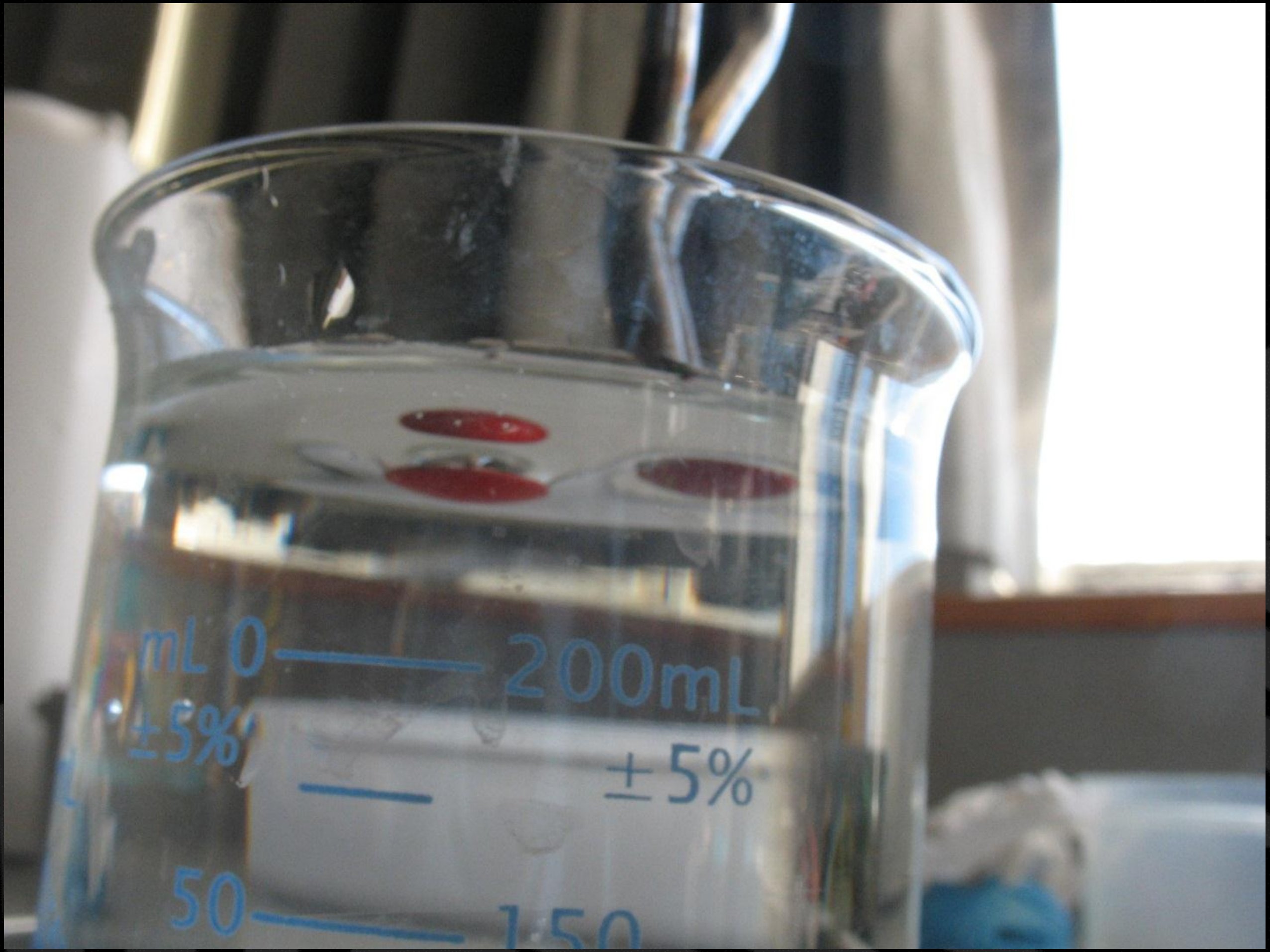
Different Shapes

Acceleration Figures

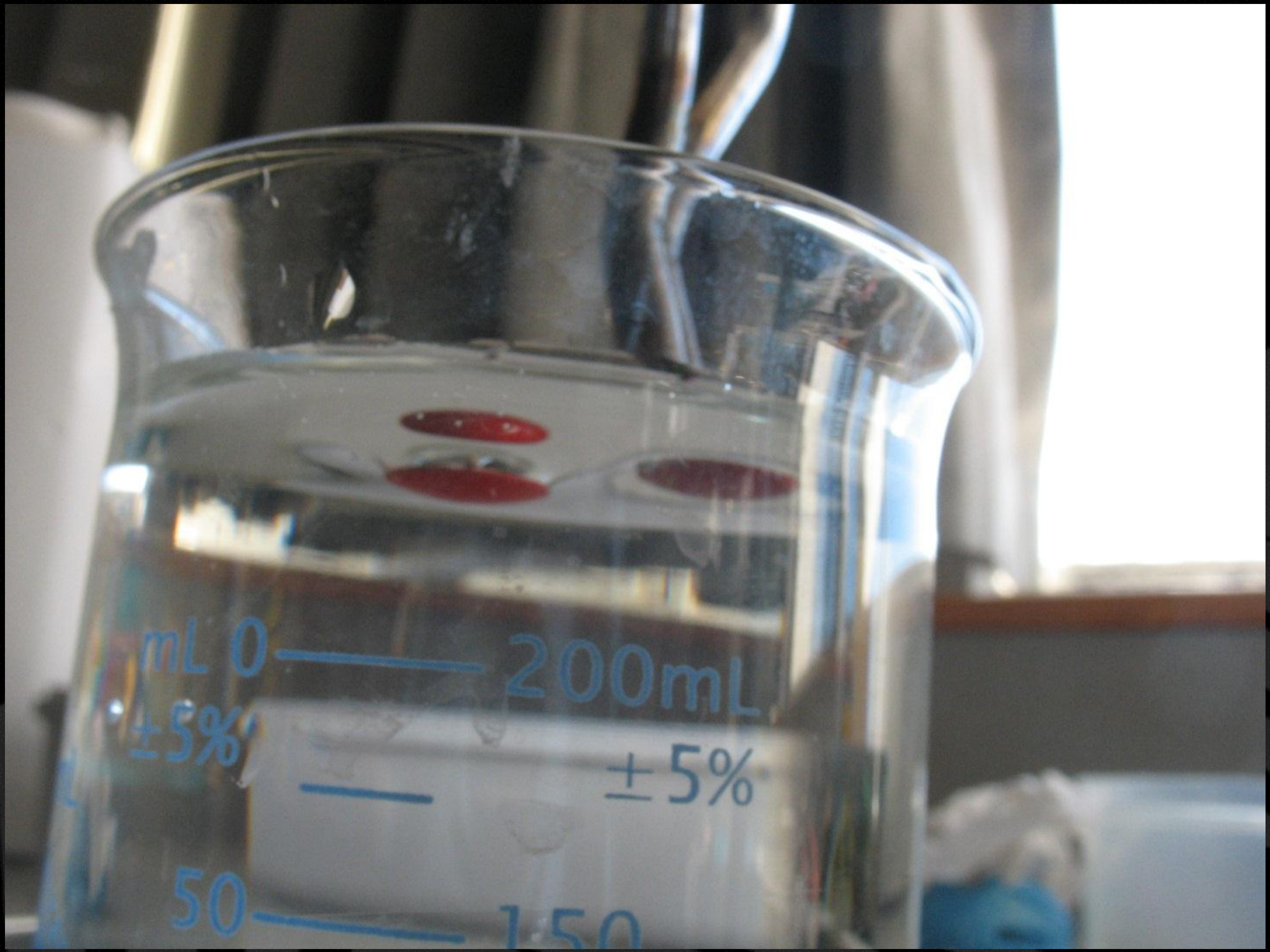
Trial	Acceleration of Pin A $/m\ s^{-2}$	Acceleration of Pin B $/m\ s^{-2}$
1	0.13	0.31
2	0.22	0.20
3	0.36	0.40
4	0.29	0.32

Maximum velocity 0.03 m s^{-1}

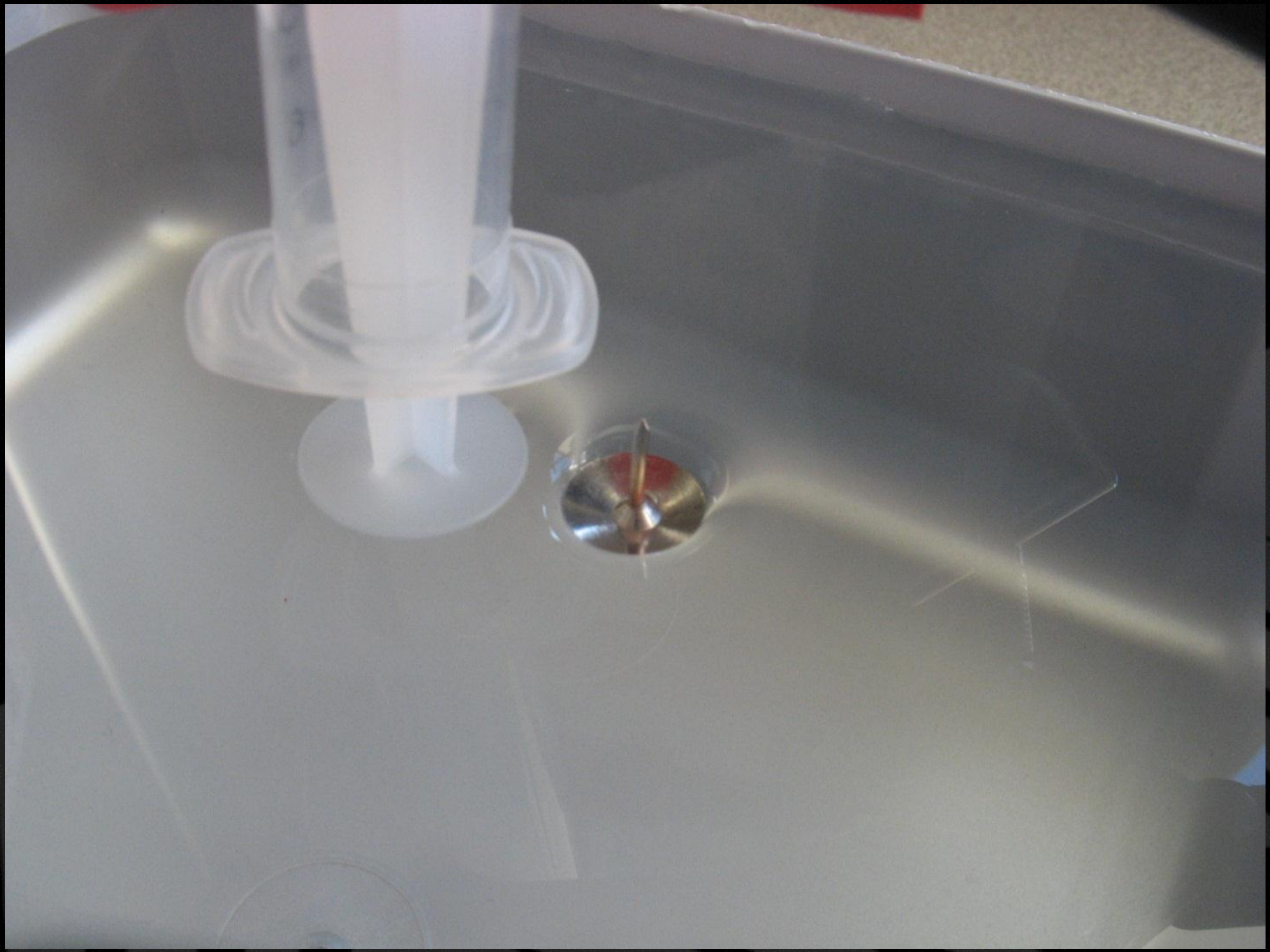
Equilibrium



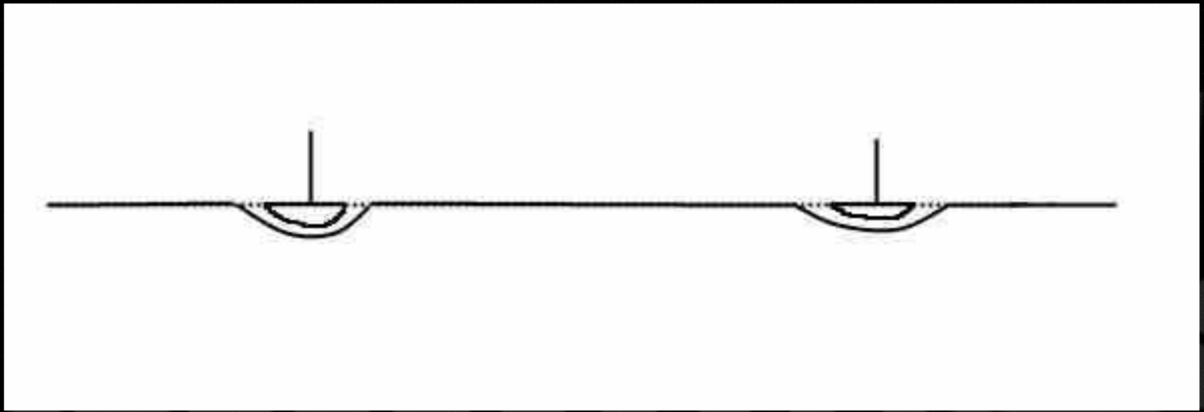
Equilibrium



Equilibrium



Theory 1



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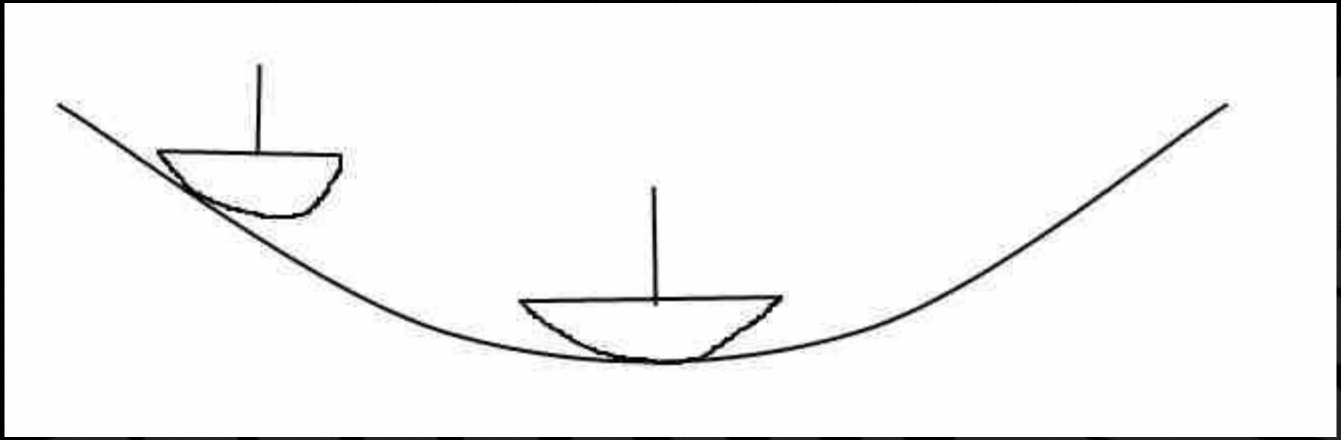

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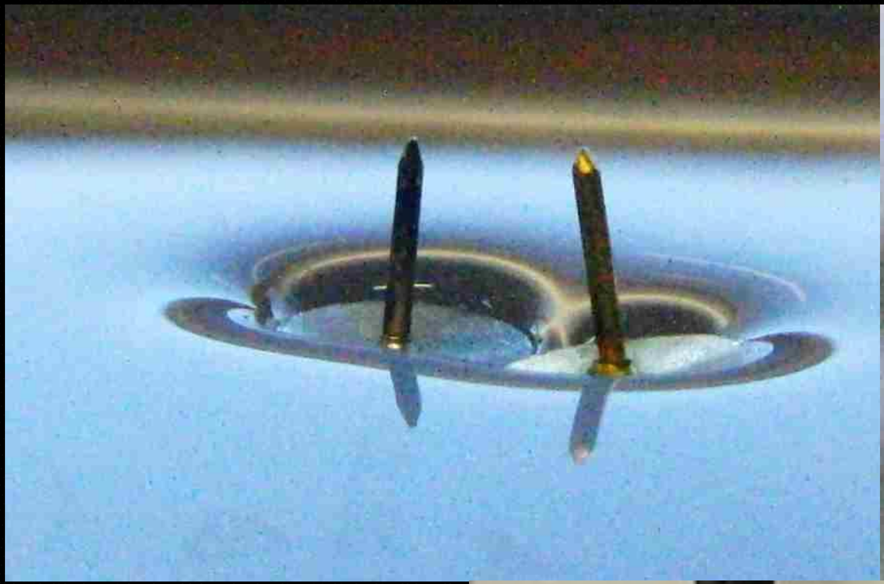

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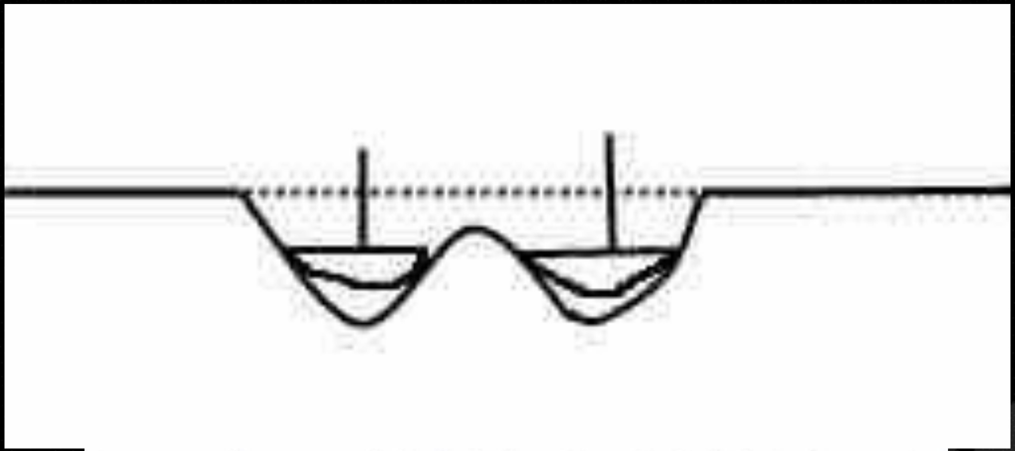
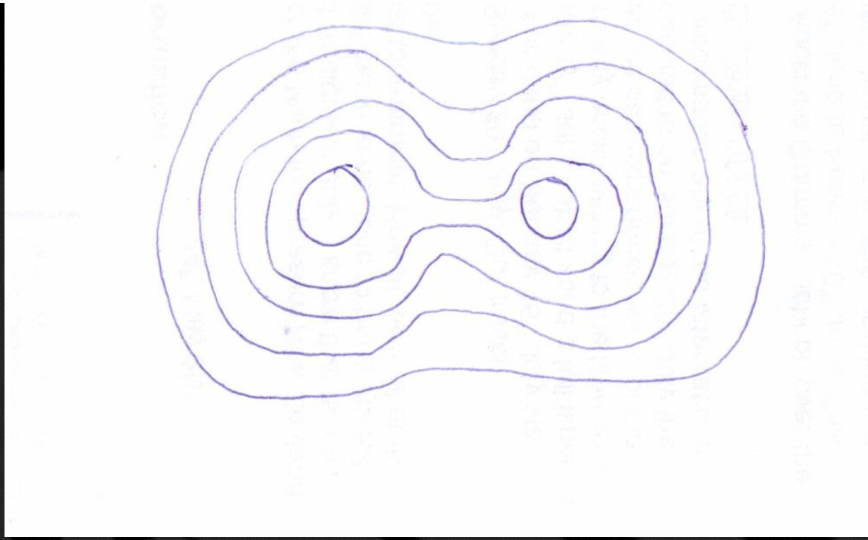
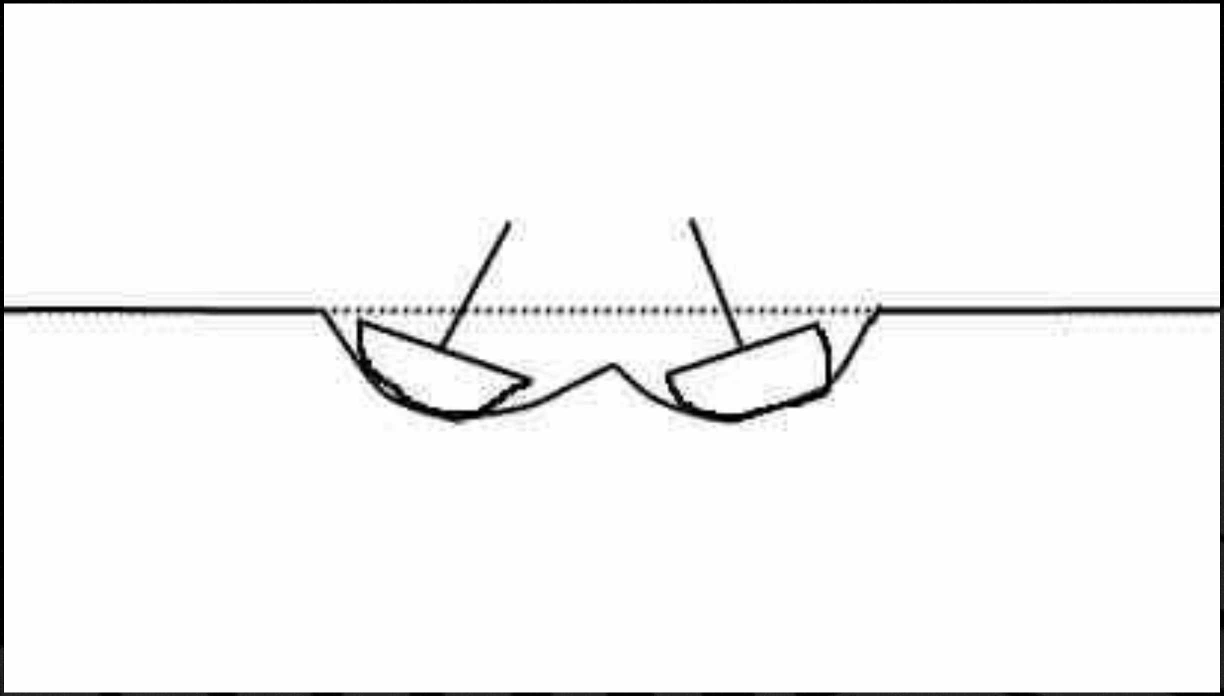




Theory 2



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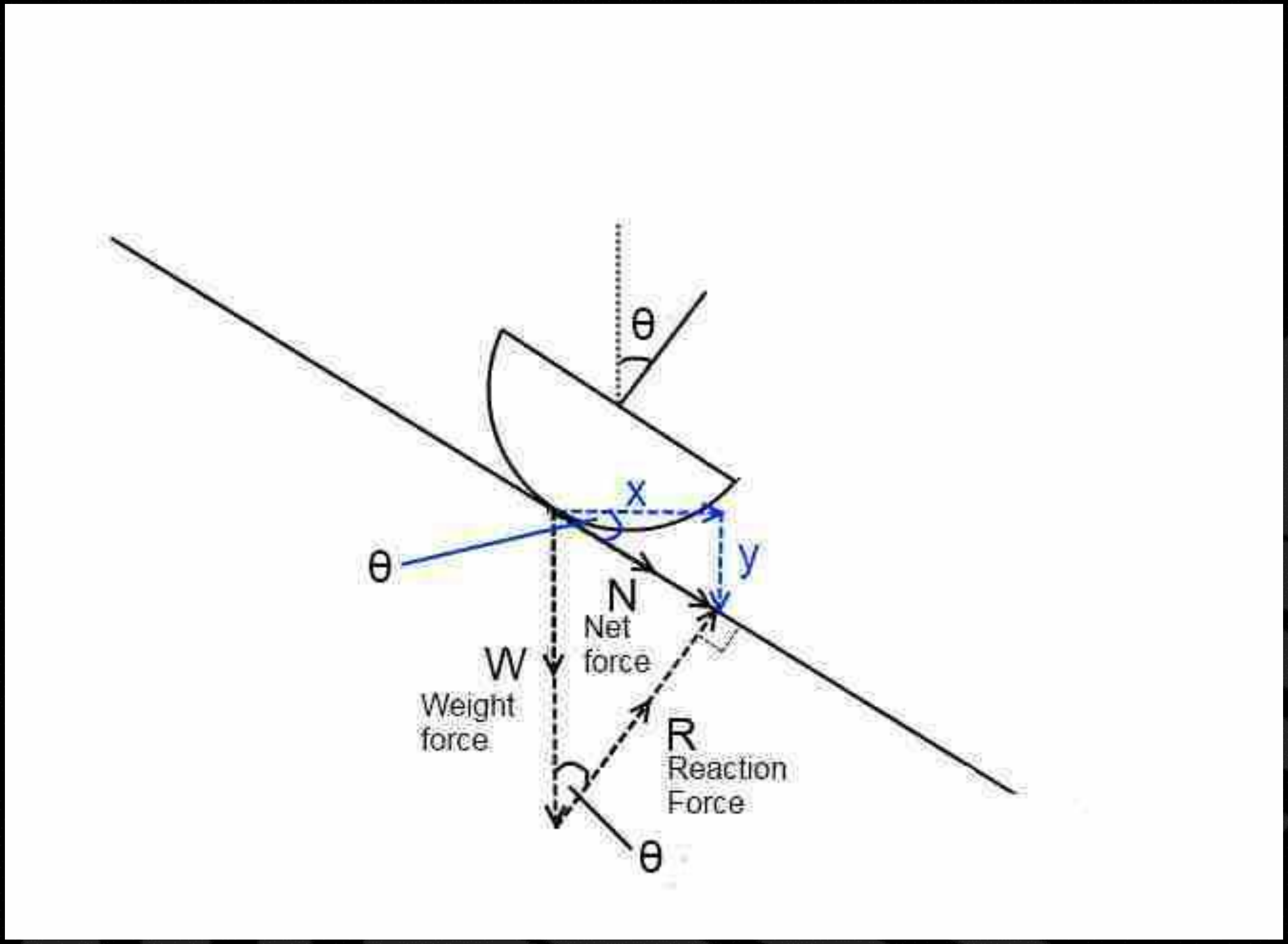

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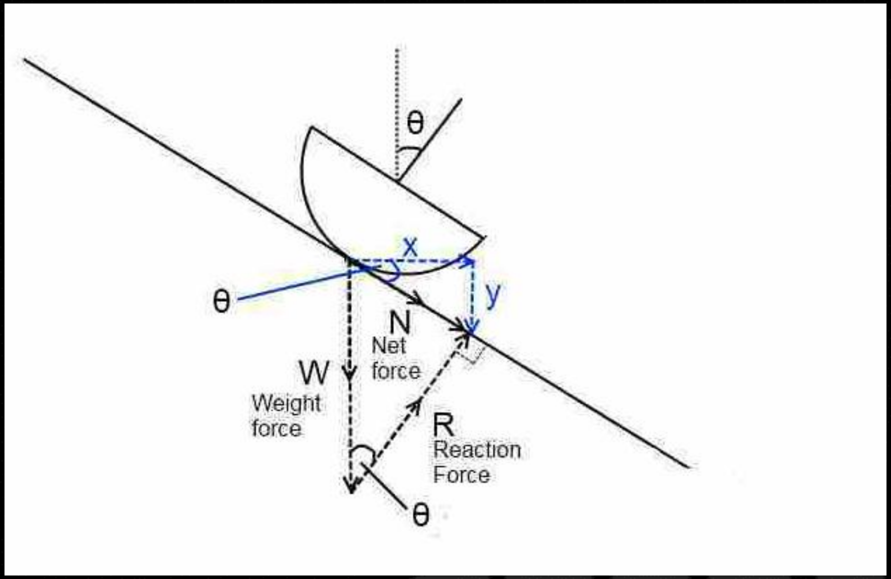


Find F_x

$$\frac{F_N}{W} = \sin\theta$$

$$\frac{F_x}{F_N} = \cos\theta$$

$$F_x = F_N \cos\theta$$

$$F_x = W \sin\theta \cos\theta$$

$$\because 2\sin A \cos A \equiv \sin 2A$$

$$\therefore F_x = \frac{1}{2} W \sin 2\theta$$

Theory 2

$$F_x = \frac{1}{2} W \sin 2\theta$$

$$ma = \frac{1}{2} W \sin 2\theta$$

m=0.32g

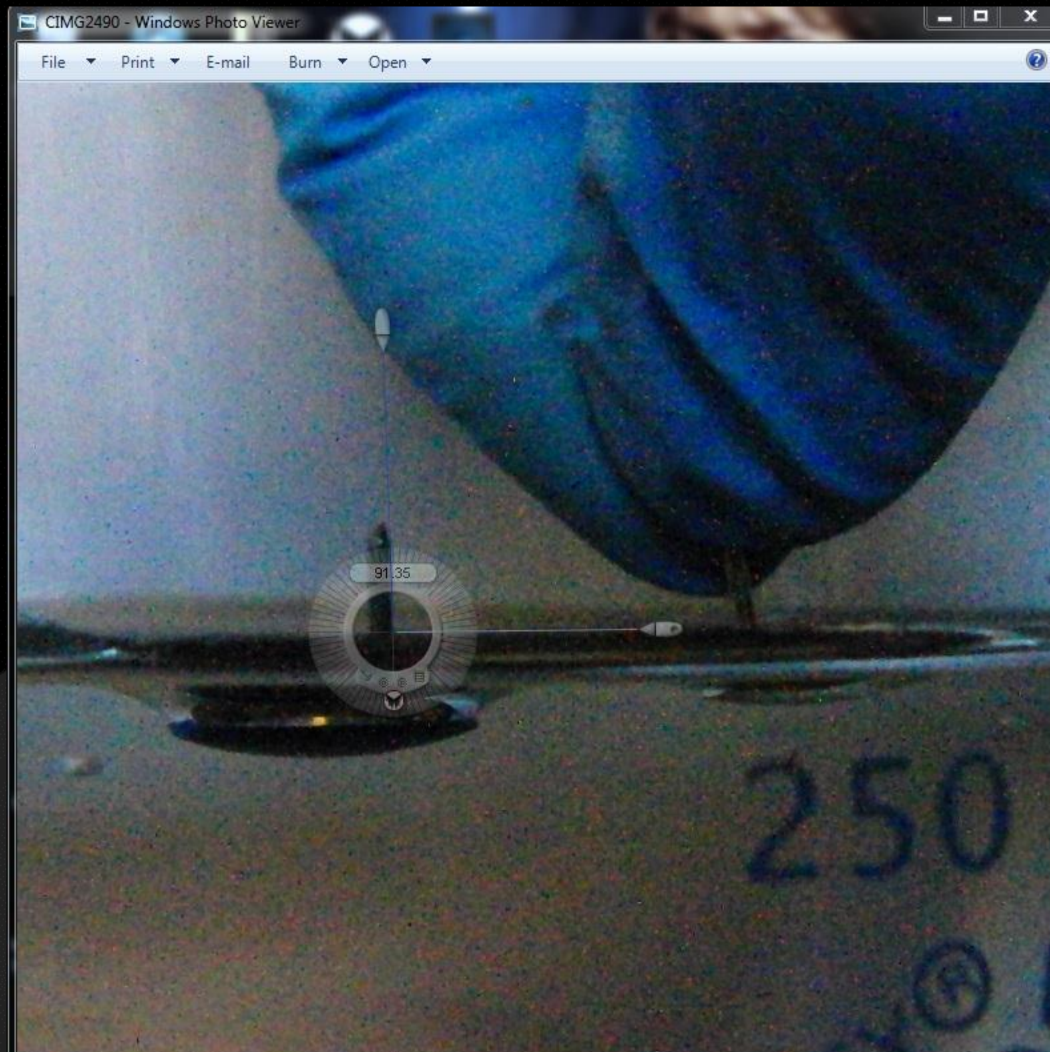
Tracker: max. acceleration =0.54 $m\ s^{-1}$

$$\theta = 3.16°$$

Theory 2

- 60 fps continuous shooting
- Enabled me to take HD photos – essential for magnification and angle measurement

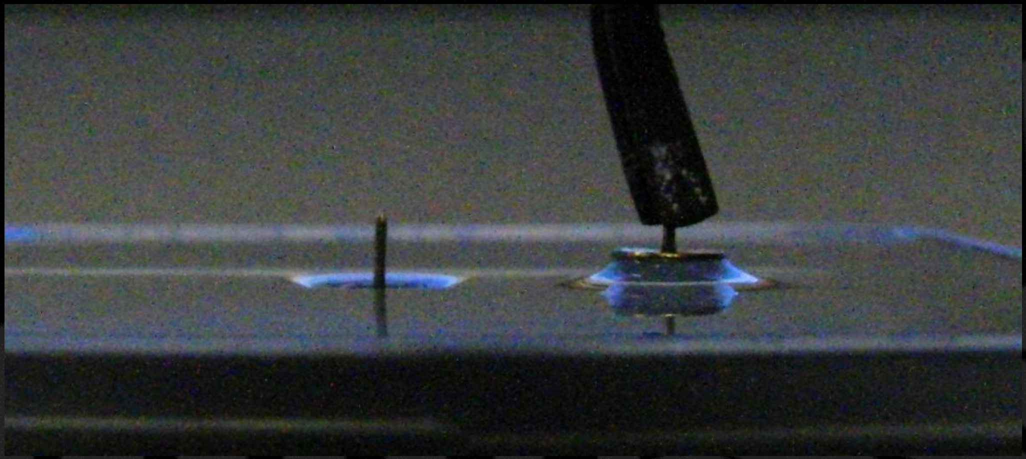
Theory 2



3.06
1.75
4.88
2.13
2.40
0.74
1.51
1.88

Theory 2

- Repulsion
- Similar method of continuous shooting



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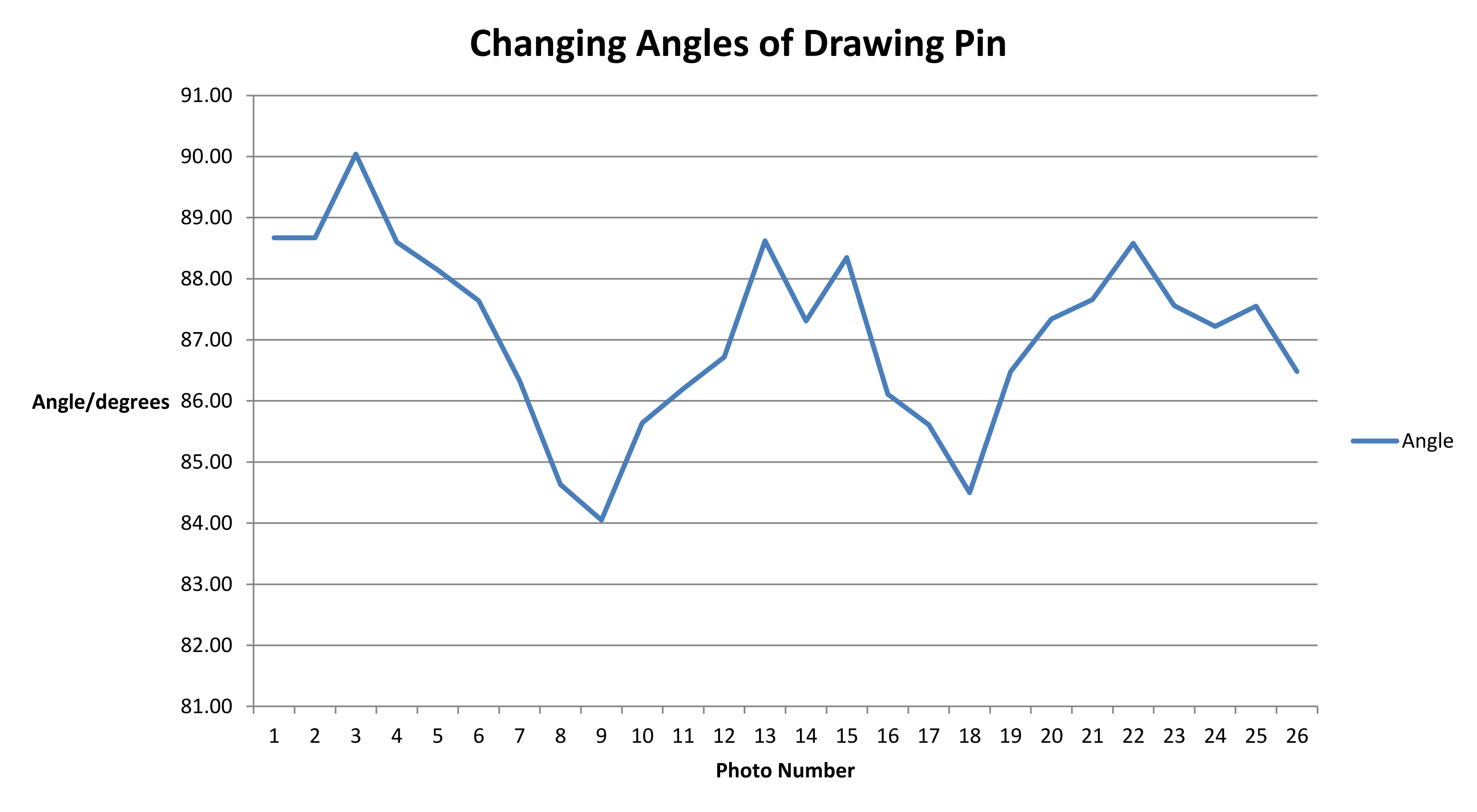
Changing Angles of Drawing Pin
Angle/degrees
91.00
90.00
89.00
88.00
87.00
86.00
85.00
84.00
83.00
82.00
81.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Photo Number
Angle

Theory 2

- Inconclusive: error quite significant: $\pm 0.5°$
- Did not have calculated values to match to each individual measured angle

Theory 3 - Energy

- Surface tension is also defined as $\gamma = \frac{E}{A}$

$$units\ of\ \frac{J}{m^2}$$

- Energy per surface area
- To minimise area, liquids tend to form spherical droplets (when free of other influences)
- Applies to small scales – γ is more significant than hydrostatic pressure differences

Theory 3 - Energy

- When wells interact, surface area is best minimised by merging and forming a lower level, instead of maintaining 2 separate wells
- The minimum area is when the 2 pins are touching, so this is what tends to happen – hence attraction

Theory 3 - Energy

- Flaws – difficulty explaining the repulsion and equilibrium effects