Preparation to the Young Physicists' Tournaments' 2011

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Habits and customs

- Originality and independence of your work is always considered as of a first priority

- There is no "correct answer" to any of IYPT problems

- Having a deep background knowledge about earlier work in a given field may certainly be a plus

- Taking ideas without citing will seemingly be a serious misconduct

- Critically distinguishing between personal contribution and common knowledge is likely to be appreciated

- Reading more in a non-native language may be very helpful

- Local libraries and institutions can always help in getting access to paid articles in journals, books and databases

- Is IYPT all about reinventing the wheel, or innovating, creating, discovering, and being able to contrast own work with earlier knowledge and achievements of others?

- Is IYPT all about competing, or about developing professional personal standards?

Important information

- The basic goal of this kit is not in providing students with a start-to-finish manual or in limiting their creativity, but in encouraging them to

  - regard their work critically,

  - look deeper,

  - have a better background knowledge,

  - be skeptical in embedding their projects into the standards of professional research,

  - and, as of a first priority, be attentive in not "re-inventing the wheel"

- An early exposure to the culture of scientific citations, and developing a responsible attitude toward making own work truly novel and original, is assumed to be a helpful practice and experience

- Even if linked from iypt.org, this file is not an official release of the IYPT, and should under no circumstances be considered as a collection (even unofficial) of "musts" or "instructions " for whatever competition

- Serious conclusions will be drawn, up to discontinuing the project in its current form, if systematic misuse of the kit is detected, such as explicit failure of citing properly, replacing own research with a compilation, or citing the kit itself as a "user guide"

- This version is a draft, that will be updated and reviewed until July 2011

- All suggestions and criticism about the draft are warmly appreciated :-)

These problems have no solution?

- "But, my dear fellows," said Feodor Simeonovich, having deciphered the handwriting. "This is Ben Beczalel's problem! Didn't Cagliostro prove that it had no solution?"

- "We know that it has no solution, too," said Junta. "But we wish to learn how to solve it."

- "How strangely you reason, Cristo… How can you look for a solution, where it does not exist? It's some sort of nonsense."

- "Excuse me, Feodor, but it's you who are reasoning strangely. It's nonsense to look for a solution if it already exists. We are talking about how to deal with a problem that has no solution. This is a question of profound principle…"

Arkady Strugatsky and Boris Strugatsky

Requirements for a successful IYPT report

- A novel research, not a survey or a compilation of known facts
- A balance between experimental investigation and theoretical analysis
- A comprehensible, logical and interesting presentation, not a detailed description of everything-you-have-performed-and-thought-about
- A clear understanding of the validity of your experiments, and how exactly you analyzed the obtained data
- A clear understanding of what physical model is used, and why it is considered appropriate
- A clear understanding of what your theory relies upon, and in what limits it may be applied
- Comparison of your theory with your experiments
- Clear conclusions and clear answers to the raised questions, especially those in the task
- A clear understanding of what is your novel contribution, in comparison to previous studies
- Solid knowledge of relevant physics
- Proofread nice-looking slides
- An unexpected trick, such as a demonstration *in situ*, will always be a plus

The jury would like to understand…

- What did you actually do?

- Why did you do it?

- How well did you do it?

- Were you able to voice important questions and provide grounded answers?

- What was your major contribution to the understanding of the phenomenon?

- Can you judge the achievements and limits of your work in an objective, skeptical and self-confident manner?

- Are you proficient in relevant physics concepts?

- Were you a self starter?

- Could you be left unsupervised?

PHYSIK

3.3.3. – 3.2.5.

PHYSIK

Is the novel research limited and discouraged by existing common knowledge and the ongoing work of competing groups? :-)

Problem No. 1 "Adhesive tape"

Determine the force necessary to remove a piece of adhesive tape from a horizontal surface. Investigate the influence of relevant parameters.

IYPT history

- **16.** Adhesive tape (14th IYPT, 2001)
    - Investigate and explain the light produced, when adhesive tape is ripped from a smooth surface.

What physical properties of commercially available tapes can be measured and precisely controlled?

[woodley wonderworks 2010]

Background reading

- Wikipedia: Pressure sensitive tape, http://en.wikipedia.org/wiki/Pressure_sensitive_tape
- C. W. Bemmels. Adhesive tapes. In: Handbook of Adhesives (ed. Irving Skeist, Huntington, New York, 1962), p. 584-592
- A. N. Gent and S. Kaang. Pull-off forces for adhesive tapes. J. App. Pol. Sci. 32, 4, 4689-4700 (1986)
- N. A. de Bruyne. The action of adhesives. Sci. Amer. 206, 114 (1962)
- N. A. de Bruyne. How glue sticks. Nature 180, 262 (1957)
- R. E. Baier, E. G. Shafrin, W. A. Zisman. Adhesion: Mechanisms that assist or impede it. Science 162, 1360 (1968)
- Z. Sun and D. A. Dillard. Three-dimensional finite element analysis of fracture modes for the pull-off test of a thin film from a stiff substrate. Thin Solid Films 518, 14, 3837-3843 (2010)
- A. J. Kinloch, C. C. Lau, and J. G. Williams. The peeling of flexible laminates. Int. J. Fracture 66, 1, 45-70 (1994)
- Z. Sun, K. T. Wan, and D. A. Dillard. A theoretical and numerical study of thin film delamination using the pull-off test. Int. J. Solids & Structures 41, 3-4, 717-730 (2004)
- A. N. Gent and S. Y. Kaang. Effect of peel angle upon peel force. J. Adhesion 24, 2-4, 173-181 (1987)
- A. Ahagon and A. N. Gent. Effect of interfacial bonding on strength of adhesion. J. Pol. Sci. B 13, 7, 1285-1300 (1975)
- A. N. Gent and A. J. Kinloch. Adhesion of viscoelastic materials to rigid substrates. 3. Energy criterion for failure. J. Pol. Sci. A 9, 4, 659 (1971)
- R.-J. Chang and A. N. Gent. Effect of interfacial bonding on the strength of adhesion of elastomers. II. Dissimilar adherends. J. Pol. Sci.: Pol. Phys. Ed. 19, 10, 1635-1640 (1981)
- B. M. Malyshev. Strength of adhesive joints using theory of cracks. Int. J. Fracture 1, 114 (1965)
- K. Kendall. Transition between cohesive and interfacial failure in a laminate. Proc. R. Soc. London A 344, 287 (1975)

Key questions

- What interactions cause the tape to stick to the surface? How to describe these interactions quantitatively?
- What parameters of the surface and the film are relevant?
- How does the force depend on the direction of pulling?
- Is the measured force constant over the time of peeling?
- How to measure the parameters of the film and the adhesive layer? How relevant they are?
- At what degree the measured forces and the motion of tape may be reproduced, if the experiment is repeated?
- Would it be difficult to develop a theory including all relevant parameters as tunable variables? Is it worth modeling the system numerically?

Problem No. 2 "Air drying"

Table utensils (dishes, cutlery, etc.), after being washed, dry differently. Investigate how the time of drying depends on relevant parameters.

IYPT history

- **9.** Air dryer (12th IYPT, 1999)
  - During 4 minutes collect as much water as possible from the air in the room. The mass of the equipment must not exceed 1 kg. The water should be collected in a glass test tube, provided by the jury.
- **8.** Condensation (20th IYPT, 2007)
  - Water droplets form on a glass filled with cold water. Explain the phenomenon and investigate the parameters that determine the size and number of droplets on the glass.
- **6.** Liquid stain (21st IYPT, 2008)
  - When a drop of liquid such as coffee dries on a smooth surface, the stain usually remains at the edge of the drop. Investigate why the stain forms at the edge and what parameters affect the characteristics of the stain.
- **9.** Drying (22nd IYPT, 2009)
  - Investigate the drying process of a vertical wet paper sheet. How does the boundary of drying move?

Large droplets, small droplets, films...?

[Jo Naylor 2010]

Background reading

- H. Stone. Manipulating thin-film flows: From patterned substrates to evaporating systems. Lecture on June 29, 2007. Diffusion des savoirs de l'Ecole Normale Superiueure. http://www.diffusion.ens.fr/data/video-mp4/2007_06_29_stone.mp4

- K. S. Birdi, D. T. Vu, and A. Winter. A study of the evaporation rates of small water drops placed on a solid surface. J. Phys. Chem. 93, 9, 3702-3703 (1989)

- Christophe Poulard, Geoffroy Guéna, Anne-Marie Cazabat, A. Boudaoud, M. Ben Amar. Rescaling the dynamics of evaporating drops (2005), arXiv:cond-mat/0505651v1 [cond-mat.soft]

- Ashutosh Sharma. Equilibrium and dynamics of evaporating or condensing thin fluid domains: Thin film stability and heterogeneous nucleation. Langmuir 14, 17, 4915-4928 (1998), http://www.iitk.ac.in/che/downloads/as/Langmuir1998_evaporation_Sharma.pdf

- R. D. Deegan, O. Bakajin, T. F. Dupont, G. Huber, S. R. Nagel, T. A. Witten. Capillary flow as the cause of ring stains from dried liquid drops. Nature, 389, 327 (1997), http://jfi.uchicago.edu/~tten/Coffee.drops/Nagel.7.4.pdf

- E. Sultan, A. Boudaoud, M. Ben Amar. Evaporation of a thin film: Diffusion of the vapour and Marangoni instabilities. J. Fluid Mech. arXiv:cond-mat/0408609v2 [cond-mat.soft] 12 Nov 2004

- Y.O. Popov and T.A. Witten. Characteristic angles in the wetting of an angular region: surface shape (2001), arXiv:cond-mat/0006387 v4 13 Aug 2001

- T. Metzger, E. Tsotsas, and M. Prat. Modern drying technology. (Wiley, New-York 2007)

Background reading

- Don Kulasiri and Ian Woodhead. On modelling the drying of porous materials: Analytical solutions to coupled partial differential equations governing heat and moisture transfer. Math. Prob. in Eng., 3, 275–291 (2005), http://www.emis.de/journals/HOA/MPE/Volume2005_3/291.pdf

- Lei Xu, Simon Davies, Andrew B. Schofield, and David A. Weitz. Dynamics of drying in 3D porous media. Phys. Rev. Let. 101, 094502 (2008), arXiv:0807.4757v1 [physics.flu-dyn]

- Reza Torabi and Mohammad Mehrafarin. Drying model for porous material based on the dynamics of the evaporation front. arXiv:cond-mat/0409384v1 [cond-mat.stat-mech]

- Hamza Chraibi, M. Prat, and O. Chapuis. Influence of contact angle on slow evaporation in two-dimensional porous media. Phys. Rev. E, 79, 026313 (2009), arXiv:0903.1738v1 [cond-mat.soft]

- Igor Mitkov, Daniel M. Tartakovsky, and C. Larrabee Winter. Dynamics of wetting fronts in porous media. Phys. Rev. E, V. 58, No. 5, R5245-R5248, Rapid Communications (1998), arXiv:patt-sol/9809004v1

Key questions

- Unlike manual washing, commercial automatic dishwashers may use rinse agents that suppress droplet formation, and also leave the objects at significantly elevated temperatures. How does the effect depends on the initial "washing" procedure, and which procedure do you establish in your research?

- How does the water initially behave on a substrate? Does it form droplets (of what mean size?), films (of what thickness?), of other structures? How does it depend on properties of surface, such as wettability? What physical forces are responsible for initial structuring of liquid on the substrate?

- Is all water deposited only on the surface? How relevant is the porosity of substrates?

- How does the liquid geometry change during evaporation? What are the time dependences for contact areas, contact angles, total mass of water? How to measure them experimentally?

- What parameters of surfaces may be relevant for the evaporation dynamics? (initial temperature? wettability? radius of curvature?)

- What parameters of liquid may be relevant for the evaporation dynamics? (surface tension? residue of detergent? density? viscosity? specific heat capacity, specific evaporation heat, boiling point?)

- Is the evaporation rate constant over time?

- How to define "evaporation"? Is it a first-order, or second-order phase transition? What happens to entropy of the system during evaporation? What are the thermodynamic aspects of the problem?

- What parameters of ambient atmosphere may influence on the effect? (air temperature and humidity? presence of air flows?) Which of these parameters need to be controlled to make experiments coherent?

- How relevant to the problem are Marangoni flows, other fluid microflows, heat transfer inside the droplets or films?

- Above all, how to determine the "time of drying" and at which point an object is already "dry"?
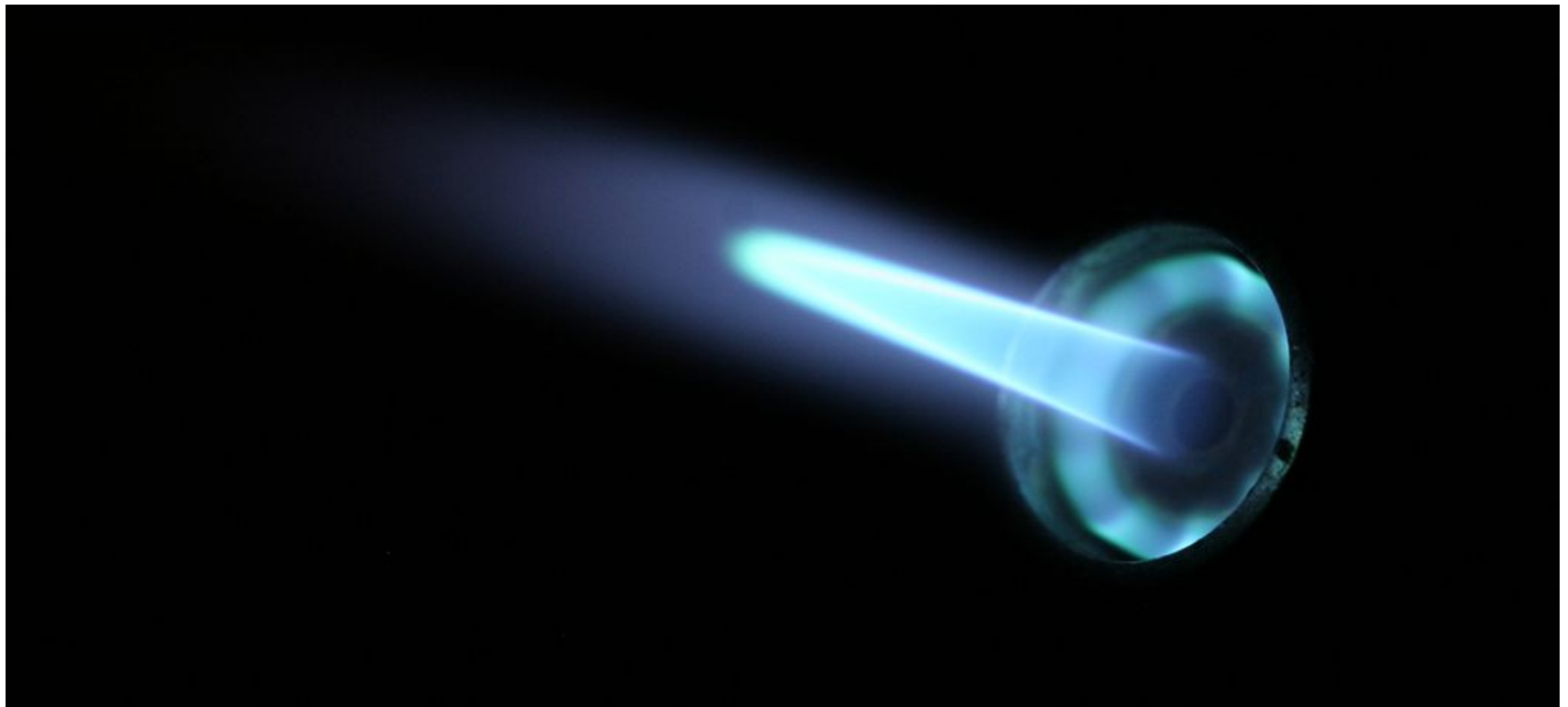
Problem No. 3 "Bouncing flame"

Place a flame (e. g. from a Bunsen burner) between two charged parallel metal plates. Investigate the motion of the flame.

(Very) basic facts

Should we systematically investigate influence on the field on flames of different combustion degree and speed, or just take one particular flame, such as of a candle?

CAUTION!
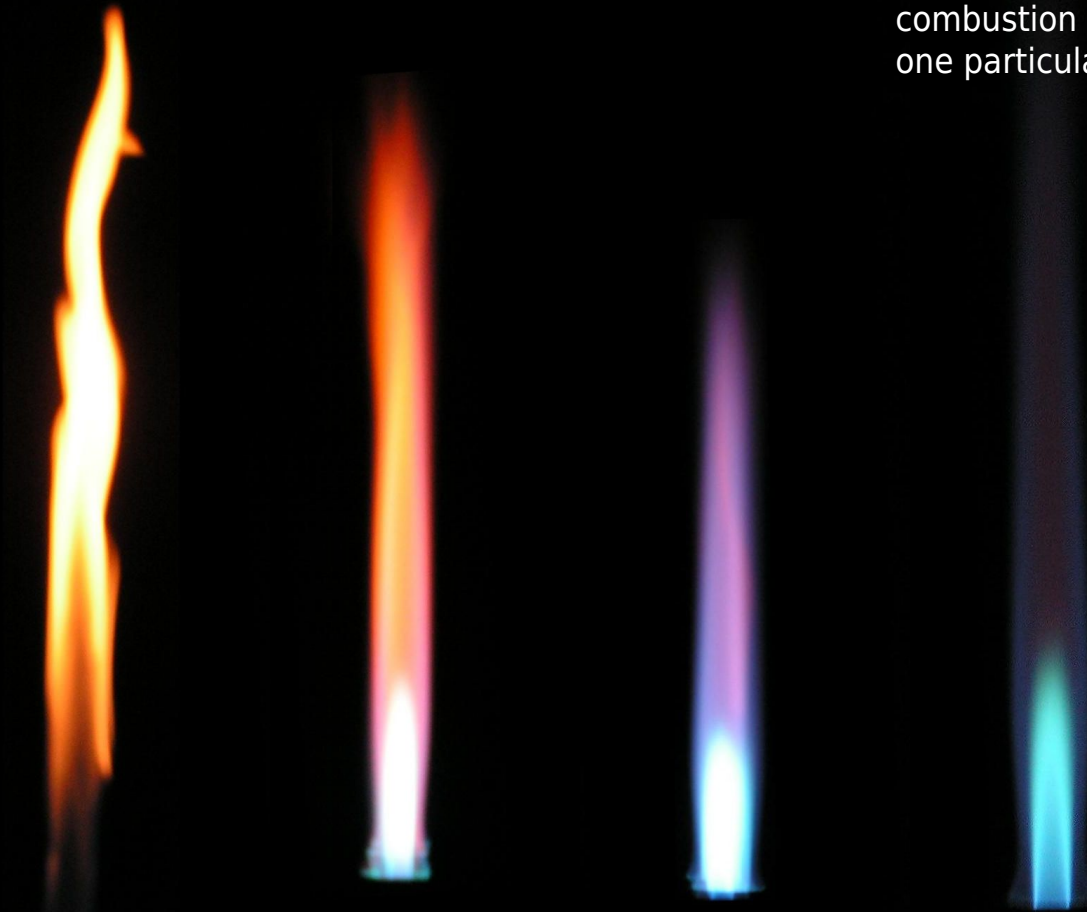
Flames are open and very hot, and electric equipment is all around!

Air valve in Bunsen burner fully closed:
Diffusion, reducing, silent, relatively cold and non-luminous flame, with incandescent soot particles

Air valve in Bunsen burner fully opened:
Premixed, oxidizing, roaring, relatively hot and luminous flame, with color due to band emission

Wichtigkeit, eine Lichtquelle von noch grösserer Unveränderlich-
keit benutzen zu können. Wir haben daher die Bedingungen
noch weiter verfolgt, unter denen Leuchtgasflammen die grösste
Unveränderlichkeit zeigen. Flammen, die aus einem gewöhn-
lichen einfachen Brenner unter einem Drucke von einigen Linien
Wasserhöhe erhalten werden, flattern und schwanken viel zu
sehr, um zu genauen Lichtmessungen dienen zu können. Schon
bessere Resultate erhält man, wenn sich der Brenner auf einem
kleinen Windkasten befindet, der als Compensator für die kleinen
Schwankungen des Gaszuflusses
dient. Vollkommen fest und con-
stant aber sind die Dimensionen der
Flammen erst dann, wenn die seit-
lichen Zuströmungen der atmosphä-
rischen Luft in den Flammenkörper
so viel als möglich gemässigt wer-
den. Dies ist am einfachsten da-
durch zu erreichen, dass man das
Gas unter einem Drucke ausströ-
men lässt, der nicht mehr als 1
bis 0,5 mm Wasserhöhe beträgt,
und dass man die in der Luft frei
brennende Flamme mit einem Kasten
umgiebt, durch welchen sie vor den
Einflüssen eines unregelmässigen
Luftzuges geschützt bleibt. Alle
diese Bedingungen finden sich in
dem Beleuchtungsapparate Fig. 5
vereinigt. $A A_1$ ist ein inwendig
geschwärzter Kasten, dessen Boden
zur Herstellung des freien Luft-
zutritts siebartig durchlöchert ist,
und dessen vordere Wand A_1 aus
einem Schieber besteht, in dessen
Mittelpunkt ein durch zwei parallele
Spiegelplatten geschlossenes, mit
Wasser gefülltes Gefäss a eingesetzt
ist. Dasselbe dient zur [80] besseren
Abhaltung der von der Flamme l
ausgehenden strahlenden Wärme.

Fig. 5.

Das Leuchtgas, welches diese Flamme speist, wird durch das
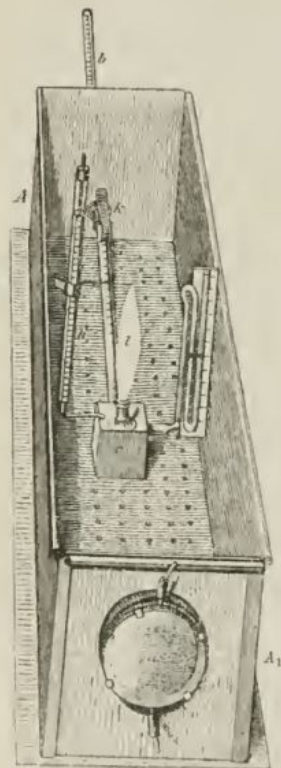zur Gasleitung dienende Glasrohr b in den kleinen Windkasten c

zu erfahren, von welchen in der Flamme vorhandenen Gemeng-
theilen die Menge der chemisch wirkenden Strahlen vornehmlich
bedingt wird. Es diente zu diesen Versuchen die Brenner-
vorrichtung, welche Einer von uns angegeben und statt der
Drahtnetzlampen im hiesigen Laboratorium eingeführt hat, und
die sich besser als irgend eine andere Vorrichtung zur Hervor-
bringung regelmässiger Flammen von verschiedener Leuchtkraft,
Färbung und Form eignet. Das Princip dieser Lampen beruht
einfach [85] darauf, dass man das Leuchtgas unter Verhältnissen
ausströmen lässt, wo es gerade so viel Luft vermöge seiner
eigenen Bewegung aspiriren und mit sich vermischen kann,
dass das gebildete lufthaltige Gasgemenge auf der Grenze steht,
wo es die Fähigkeit eben noch
nicht erlangt hat, die Entzündung
durch sich hindurch fortzu-
pflanzen. Diese Bedingung wird
durch folgende einfache Vorrich-
tung erfüllt. a Fig 6 ist ein ge-
wöhnlicher Kreuzschnittbrenner[*]),
der sich im Mittelpunkte der cy-
lindrischen Höhlung b, zu gleicher
Höhe mit der Oberfläche des
Würfels $cccc$ erhebt. Dieser cy-
lindrische Raum b, der 15^{mm} tief
ist und 10^{mm} im Durchmesser hat,
communicirt mit der äusseren Luft
durch vier 7^{mm} im Durchmesser
haltende Löcher dd. Wird die
8,5^{mm} weite, 76^{mm} lange Röhre ee_1
in den Cylinder b eingeschraubt
und lässt man das Leuchtgas von
dem Brenner a durch dieselbe
strömen, so saugt es durch die
Oeffnungen d so viel Luft auf, dass
es an der Mündung der Röhre e
mit nicht leuchtender völlig russ-
freier Flamme verbrennt. Die

Fig. 6.

Helligkeit des so mit Luft vermischten Gases übertrifft kaum die
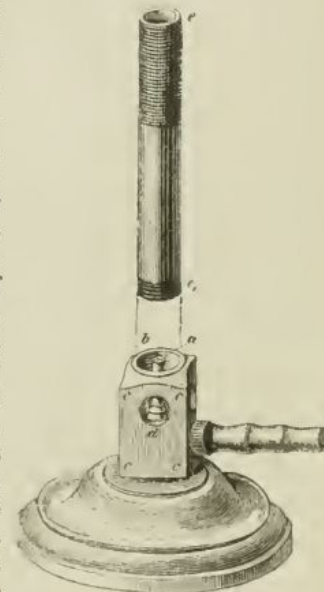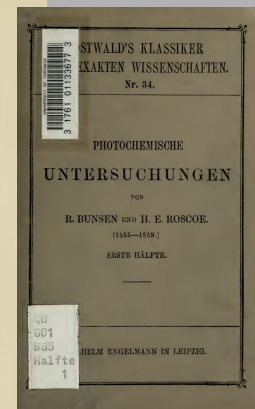einer Wasserstoffflamme. Nach Verschluss der Oeffnungen d

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[*]) Aus einem solchen Brenner strömt das Gas in drei divergiren-
den Flammen aus, deren Spitzen in die Scheitel eines gleichseitigen
Dreiecks fallen.

IYPT history

- **13.** Gas flow (12th IYPT, 1999)
  - Measure the speed distribution of the gas flow in and around the flame of a candle. What conclusions can be drawn from the measurements?
- **3.** Plasma (13th IYPT, 2000)
  - Investigate the electrical conductivity of the flame of a candle. Examine the influence of relevant parameters, in particular, the shape and polarity of the electrodes. The experiments should be carried out with a voltage not exceeding 150 V.

from the effects due to the flame alone. The following simple experiments will however serve to illustrate the electrical properties of flames.

Place an ordinary coal gas flame between two parallel metal

plates so that there is a space of half a centimeter or so on each side of the flame between it and the plates. Charge one of these plates to a high positive potential and the other to a high negative potential by a set of accumulators. Observe that the outer part of the flame where the most combustion takes place is drawn towards the negative plate while the or cooler part of the flame is attracted to the posi showing that the hotter part is positively charged cooler part is negatively electrified.

In a Bunsen flame place the ends of two platin and connect one of these through a sensitive D'Ars vanometer to one pole of a storage battery of only a few

Background reading

- Wikipedia: Bunsen burner, http://en.wikipedia.org/wiki/Bunsen_burner
- R. Bunsen und H. E. Roscoe. Photochemische Untersuchungen (erste Hälfte, Engelmann, Lepizig, 1892),
http://ia600304.us.archive.org/17/items/photochemischeun01bunsuoft/photochemischeun01bunsuoft.pdf
- Wikipedia: Diffusion flame, http://en.wikipedia.org/wiki/Diffusion_flame
- Wikipedia: Premixed flame, http://en.wikipedia.org/wiki/Premixed_flame
- Wikipedia: Oxidizing and reducing flames, http://en.wikipedia.org/wiki/Oxidizing_and_reducing_flames
- Richard Manliffe Sutton. Demonstration Experiments in Physics (McGraw-Hill Book Company, 1938),
http://physicslearning.colorado.edu/PIRA/Sutton/PARTVI.pdf,
http://physicslearning.colorado.edu/PIRA/Sutton/PARTIV.pdf
- G. D. Freier and F. J. Anderson. Demonstration Handbook for Physics (American Association of Physics Teachers, 1981)
- Harry F. Meiners. Physics Demonstration Experiments, Vol. I (The Ronald Press Company, New York, 1970)
- Ions produced by a flame carry a current (practicalphysics.org, May 2006),
http://www.practicalphysics.org/go/Experiment_522.html
- Ions in a flame (practicalphysics.org, August 2007),
http://www.practicalphysics.org/go/Experiment_289.html
- Robert Kenning McClung. Conduction of Electricity Through Gases and Radio-Activity: A Text-Book with Experiments (P. Blakiston's son & Co., Philadelphia, 1909), pp. 115-117,
http://books.google.com/books?id=GZAy2SypZzcC&pg,
http://www.archive.org/download/conductionofelec00mcclrich/conductionofelec00mcclrich.pdf

Background reading

- A. von Engel and J. R. Cozens. Flame plasmas. In: Advances in electronics and electron physics (ed. L. L. Marton, Academic Press, 1964), pp. 99-146, http://books.google.com/books?id=0Mndi2cCMuUC&
- Electric field effect on flame (youtube, from Ontivorsaurus, April 13, 2007), http://www.youtube.com/watch?v=MPFkp2HrEcs
- Electric field effect on flame (youtube, from Ontivorsaurus, April 13, 2007), http://www.youtube.com/watch?v=6fKGeV4NrrA
- K. G. Payne and F. J. Weinberg. A preliminary investigation of field-induced ion movement in flame gases and its applications. Proc. Royal Soc. London A: Mathematical and Physical Sciences 250, 1262, 316-336 (1959)
- Jing Hu, Boris Rivin, Eran Sher. The effect of an electric field on the shape of co-flowing and candle-type methane-air flames. Exp.Therm. Fluid Sci. 21, 124-133 (2000)
- Eugene V. Vega and Ki Yong Lee. An experimental study on laminar $CH_4/O_2/N_2$ premixed flames under an electric field. J. Mech. Sci. Tech. 22, 312-319 (2008)
- William B. Jensen. The origin of the Bunsen burner. J. Chem. Educ. 82, 4, 518 (2005)
- Is fire a plasma (discussion @ physicsforums.com), http://www.physicsforums.com/archive/index.php/t-203289.html
- Wikipedia: Flame ionization detector, http://en.wikipedia.org/wiki/Flame_ionization_detector
- Axel Vincent-Randonnier, Serge Larigaldie, Philippe Magre and Vladimir Sabel'nikov. Plasma assisted combustion: effect of a coaxial DBD on a methane diffusion flame. Plasma Sources Sci. Technol. 16 149 (2006)
- C. S. MacLatchy. Langmuir probe measurements of ion density in an atmospheric-pressure air-propane flame. Combustion and Flame 36, 171-178 (1979)
- A. M. Starik. Formation of charged nanoparticles in hydrocarbon flames: principal mechanisms. Plasma Sources Sci. Technol. 17, 045012 (2008)

Key questions

- What are the key differences between various types of flames, such as diffusion flame and premixed flame? Does the task specify that only a fixed, particular, type of flame need to be analyzed?
- What information can be retrieved from color, rate of flickering, and other visible parameters of the flame?
- What is the temperature field, concentration of charge carriers, fluid viscosity, and other physical parameters, inside the flame? How to measure them?
- Many people and sources argue if flames are plasmas or not. Is there a general scientific consensus on the point? If not, what are the basic arguments of both sides?
- Different flames may have not only different distribution and concentration of charge carriers, but also different vertical airflow speed. How does the behavior in electric field depends on all these parameters?
- What possible types of "bouncing" in electric field can be observed? Is a logical, physically validated classification possible?
- Why the flame may move as a whole, if the electric field acts on the charge carriers only? What acts as a restoring force, if the flame "oscillates"?

[conskeptical 2008]

Problem No. 4 "Breaking spaghetti"

Find the conditions under which dry spaghetti falling on a hard floor does not break.
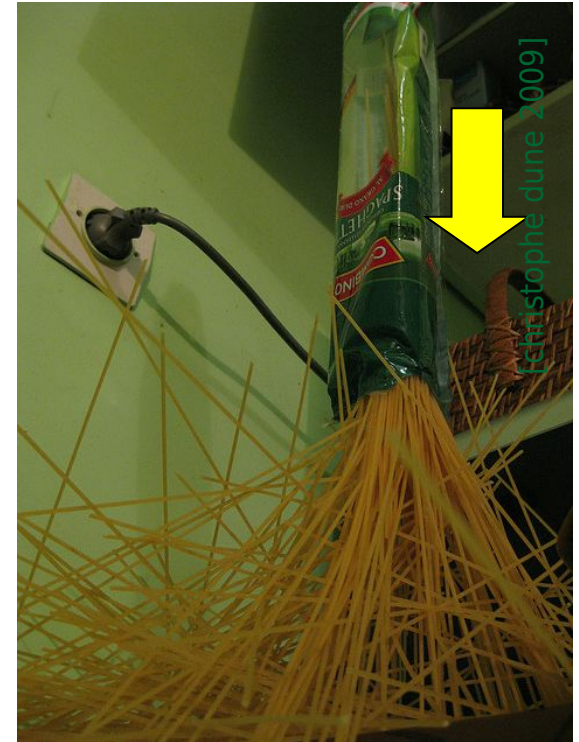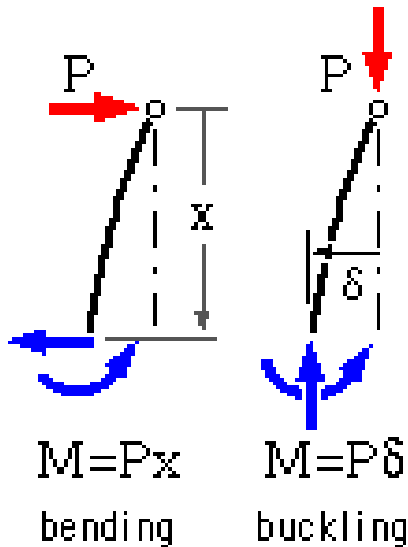
Curved spaghetti are likely to break into multiple pieces →
2006 Ig Nobel Prize in Physics awarded to Sébastien Neukirch and Basile Audoly
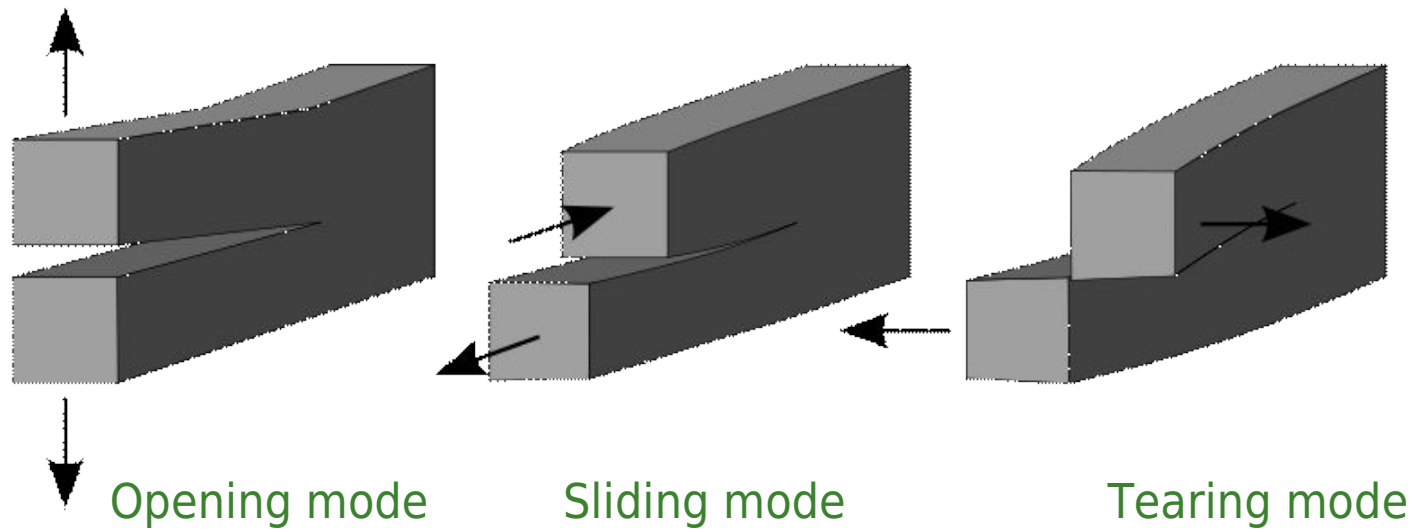
Spaghetti hits the floor...

- vertically...?
- horizontally...?
- inclined, under a certain angle...?

- For what time is the spaghetti subject to impact load, and how do the stresses depend on time, in different points?

$M = Px$
bending

$M = P\delta$
buckling

Bending deformation is usually proportional to the load

Buckling is a displacement of a structure (subjected usually to compression) transverse to the load. Moments, deflections and stresses are not proportional to loads
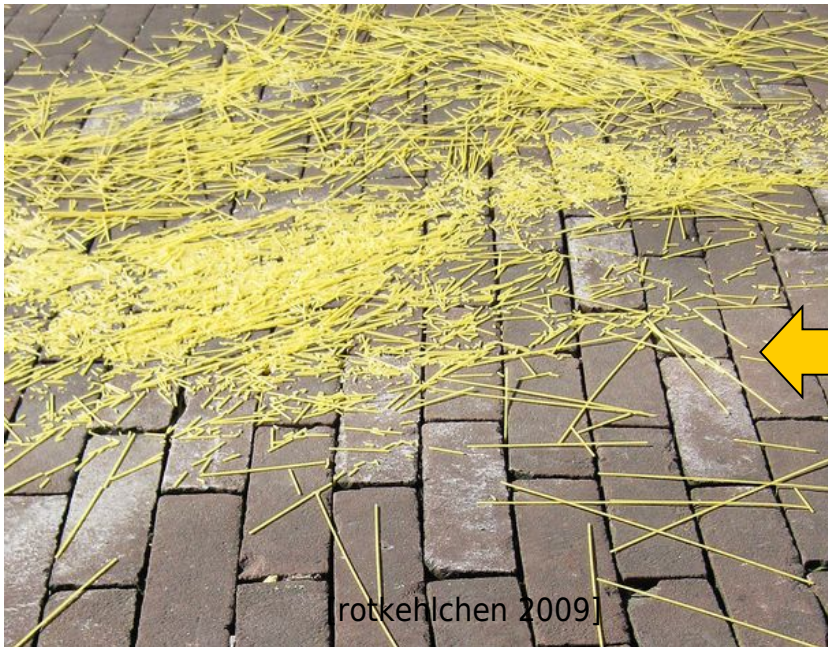
Fracture modes in spaghetti?

Opening mode   Sliding mode   Tearing mode

J.R. Gladden & A. Belmonte, Penn State (2003)

- Longitudinal compression causes buckling

http://www.lmm.jussieu.fr/~neukirch/work-images/spaghetti/animation_10.gif

Chances to break?

[Little Black Pot 2007]

[rotkehlchen 2009]

- Harder floor or more fragile spaghetti?
- Different impact speed, angular velocity?
- Different impact angles?
- A single rod or bulk?

Is it worth speaking of a probability of fracture, under given conditions? Is it possible to measure and/or theoretically predict it?

- How about posing a reverse problem: what information about the impact can be retrieved from the spaghetti debris?

Background reading

- B. Audoly and S. Neukirch. Fragmentation of brittle rods: why spaghetti do not break in half. Phys. Rev. Lett. 95, 095505 (2005), http://www.lmm.jussieu.fr/spaghetti/audoly_neukirch_fragmentation.pdf
- B. Audoly and S. Neukirch. Fragmentation of rods by cascading cracks: Why spaghetti does not break in half. Phys. Rev. Lett. 95, 095505 (2005)
- J. R. Gladden, N. Z. Handzy, A. Belmonte, and E. Villermaux. Dynamic buckling and fragmentation in brittle rods. Phys. Rev. Lett. 94, 035503 (2005), http://www.math.psu.edu/belmonte/PaperFile/PRL_pasta.pdf
- C. Sykes (ed.) No ordinary genius: the illustrated Richard Feynman (WW Norton & Co., New York, 1996), pp. 180-181
- G. V. Guinea, F. J. Rojo, and M. Elices. Brittle failure of dry spaghetti. Eng. Failure Analysis 11, 705-714 (2004)
- P. Weiss. That's the way the spaghetti crumbles. Science News 168, 20, 315-316 (2005) , http://www.sciencenews.org/view/feature/id/6760/title/Thats_the_Way_the_Spaghetti_Crumbles
- Brainiac Science Abuse - Spaghetti Breaking In Slow Motion (youtube, Sept. 20, 2008, from brainiacstore), http://www.youtube.com/watch?v=Ezm6bliJgPc
- Sébastien Neukirch. Dynamics and fragmentation of fragile bent rods (Institut Jean le Rond d'Alembert), http://www.lmm.jussieu.fr/~neukirch/spaghetti.html
- B. Audoly and S. Neukirch. How bent spaghetti break (Institut Jean le Rond d'Alembert), http://www.lmm.jussieu.fr/spaghetti/index.html
- Spaghetti snapped at 420 fps with Casio EX-FH20 High Speed Camera (youtube, from lainp1211, January 1, 2009), http://www.youtube.com/watch?v=kuofWlxfUSE

Background reading

- B. Audoly and S. Neukirch. How bent spaghetti break (Institut Jean le Rond d'Alembert), http://www.lmm.jussieu.fr/spaghetti/index.html
- An Introduction to the Fracture Mechanics of Spaghetti (BBC, January 2, 2009), http://www.bbc.co.uk/dna/h2g2/A44342651
- R. W. D. Nickalls. The dynamics of linear spaghetti structures — how one thing just leads to another :-) (nickalls.org, June 14, 2006), http://www.nickalls.org/dick/papers/spaghetti/spaghetti.pdf
- O. J. Nickalls and R. W. D. Nickalls R.W.D. Linear spaghetti. New Scientist 145, 52 (February 18, 1995)
- Josh Gladden, Nestor Handzy, Andrew Belmonte, and Emmanuel Villermaux. Dynamic buckling and breaking of thin rods (W. G. Pritchard Laboratories, Penn State University), http://www.math.psu.edu/belmonte/spaghetti.html
- Richard Feynman breaking spaghetti video, http://heelspurs.com/feynman.html
- Introduction on buckling (Mechanical and Chemical Engineering, the University of Western Australia), http://school.mech.uwa.edu.au/~dwright/DANotes/buckling/home.html
- C. D'Andrea and E. Gomez. The broken spaghetti noodle. Am. Math. Monthly (June-July 2006)
- M. O'Hare. Pasta puzzle. In: How to fossilise your hamster and other amazing experiments for the armchair scientist (Macmillan, UK, 2008), pp. 7–12
- R. A. Tenenbaum. Fundamentals of Applied Dynamics (Springer, 2004)
- Geoff. The Fracture Modes of Spaghetti (gmilburn.ca, July 14, 2008), http://www.gmilburn.ca/2008/07/14/the-fracture-modes-of-spaghetti/
- O. J. Nickalls and R. W. D. Nickalls. Pasta puzzle: Why does spaghetti break into three pieces? New Scientist 160, 101 (December 12, 1998)

Key questions

- Unlike the well-studied phenomenon of spaghetti breaking under gradual, controlled bending, we have an instant impact stress. What is common and what is different in these two situations? What is the time lag between initial contact and final rupture? What are the time scales for deformation and fracture?

- How to measure the mechanical properties of the spaghetti you work with? How do these properties vary among different brands?

- What are the ultimate criteria for fracture? (stress limits?)

- If a spaghetti falls with a random spatial orientation, what is the probability of fracture? Is there a way to determine the probability experimentally?

- How to measure, control or predict the impact and fracture dynamics?

- How to best record the process (with high-speed camera?)

- What is the role of the friction between the spaghetti and the floor in case of non-horizontal orientation at impact? Are surface roughnesses relevant?

- How hard is a "hard" floor? What of its parameters can be controlled?

- At what degree the effect is reproducible, if the experiment is repeated under "identical" conditions?

"Final optimization"...?

- What is the safest impact speed? (less seems better :-))
- What is the safest impact angle? (why? what maximum stresses are expected for different impact angles?)
- What are the mechanical properties for a floor to be still considered "hard"?
- What is the minimum safe curvature for a spaghetti to withstand?
- Above all, if all conditions are fulfilled and all parameters are optimized, what is the probability of fracture?

Problem No. 5 "Car"

Build a model car powered by an engine using an elastic air-filled toy-balloon as the energy source. Determine how the distance travelled by the car depends on relevant parameters and maximize the efficiency of the car.

IYPT history

- **10.** Sound cart (15th IYPT, 2002)
  - Construct and demonstrate a device that can be propelled solely by sound. Investigate its properties. Study this effect and use a model to explain it.
- **8.** Wind car (18th IYPT, 2005)
  - Construct a car, which is propelled solely by wind energy. The car should be able to drive straight into the wind. Determine the efficiency of your car.
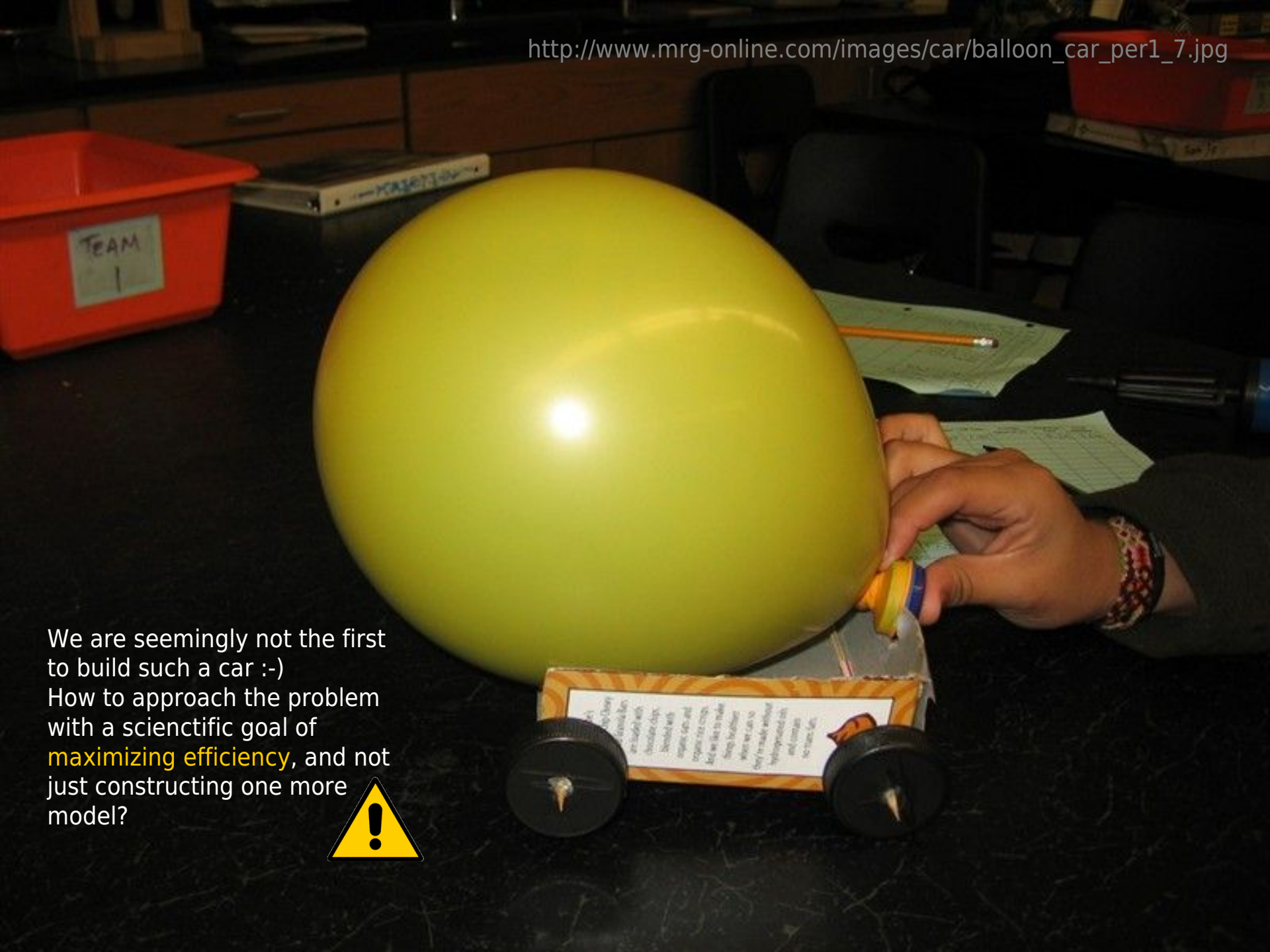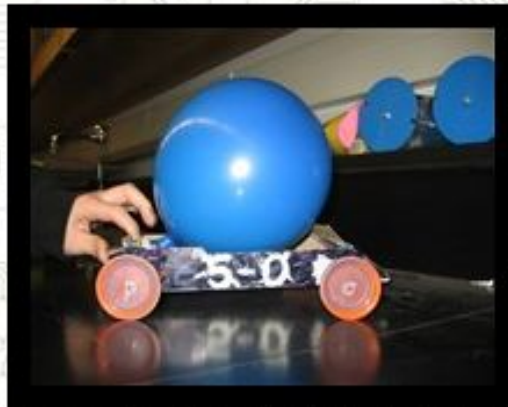
We are seemingly not the first to build such a car :-)
How to approach the problem with a scienctific goal of maximizing efficiency, and not just constructing one more model?

Ballon Powered Car Project

2007 Fastest Speed Winner

2.39 Meters per Second

2007 Total Distance Winner

21.31 Meters

Background reading

- Wikipedia: Mullins effect, http://en.wikipedia.org/wiki/Mullins_effect
- Sean Gardinier. Ballon powered car project (mrg-online.com), http://www.mrg-online.com/car.htm
- Balloon Car Contest at NASA's Jet Propulsion Laboratory, http://www.balloonhq.com/balloon_car/balloon_car.html
- Teacher Information: Rocket Car (NASA, 1996), http://er.jsc.nasa.gov/seh/Rocket_Car.pdf
- The balloon car (pbskids.org), http://pbskids.org/zoom/games/ballooncar/index.html, http://www-tc.pbskids.org/zoom/printables/activities/pdfs/ballooncar.pdf
- Balloon powered car (Queatacon), http://www.questacon.edu.au/html/squad_activities/balloon_powered_car.html
- Balloon powered car (youtube, from QuestaconNSTC, January 06, 2009), http://www.youtube.com/watch?v=3Dw6N0Tn_sU
- Balloon Rocket Car + Video (Home Science Tools), http://www.hometrainingtools.com/balloon-rocket-car-project/a/1346/
- Balloon Powered Race Cars (Middleschoolscience.com), http://www.middleschoolscience.com/balloonracers.htm
- Rocket car (University of Michigan, 1998), http://web.archive.org/web/20020601202245/http://www.eecs.umich.edu/mathscience/funexperiments/agesubject/lessons/other/rocket_car.html
- Balloon Vehicle (2001), http://web.archive.bibalex.org/web/20040804015459/http://www.kyrene.k12.az.us/schools/Pueblo/Tech/balloon_car.htm
- How to Build a Cool Balloon Powered Mini Car (youtube, from J2CMagic, April 13, 2008), http://www.youtube.com/watch?v=seaUNlrSK0Q

Background reading

- Toy Car Powered by Helium Balloons (youtube, from DavidHydeCostello, April 22, 2008), http://www.youtube.com/watch?v=dQDJvfu3G90
- Balloon Car (youtube, from evanstuartesc, February 08, 2008), http://www.youtube.com/watch?v=OewYUTDcQ2E
- Physics Balloon Car Races 2007 (youtube, from cdmtrident, January 20, 2008), http://www.youtube.com/watch?v=uIN59--CV6c
- Balloon Car Contest (youtube, Papapodcasts, April 08, 2009), http://www.youtube.com/watch?v=RMJ4ut2qBjE
- Dean J. Campbell and Stacy DeWees. An alcohol rocket car—A variation on the "whoosh bottle" theme. J. Chem. Educ. 78 (7), 910 (2001)
- Ingo Müller, Peter Strehlow. Rubber and rubber balloons: paradigms of thermodynamics (Springer, 2004), http://books.google.com/books?id=5h_3MEd3QeMC
- Yan Levin and Fernando L. da Silveira. Two rubber balloons: Phase diagram of air transfer. Phys. Rev. E 69, 051108 (2004), http://www.if.ufrgs.br/~levin/Pdfs.dir/PRE51108.pdf
- Alan Needleman. Inflation of spherical rubber balloons. Int. J. Solids Structures 13, 5, 409-421 (1977)
- M. A. Johnson and F. A. Beatty. The Mullins effect in equibiaxial extension and its influence on the inflation of a balloon. Int. J. Eng. Sci. 33, 2, 223–245 (1995)
- J. Diani, B. Fayolle, and P. Gilormini. A review on the Mullins effect, Eur. Polym. J. 45, 601–612 (2009)
- D. De Tommasi, S. Marzano, G. Puglisi, G. Zurlo, Damage-induced shape transitions in inflated rubber balloons.
- R. Jiusheng. Elastic instability of pseudo-elastic rubber balloons, Comp. Mat. Cont. 212, 1-7 (2009)
- Alan Needleman. Inflation of spherical rubber balloons. Int. J. Sol. Struct. 13, 409–421 (1977)
- H. Alexander. Tensile instability of initially spherical balloons. Int. J. Eng. Sci. 9, 151–162 (1971)
- M. Pagitz. The future of scientific ballooning. Philos. Trans. R. Soc. A 365, 3003–3017 (2007)
- E. Verron and G. Marckmann. Numerical analysis of rubber balloons. Thin-walled Struct. 41, 731-746 (2003)

Key questions

- The elastic properties of a balloon gradually change with each new launch of the car. For how many times can we use a single balloon? How do the elastic properties of a balloon determine the pressure inside and other relevant parameters? What is the Mullins effect, and is it relevant?

- How ethical and appropriate is a "verbalist" solution that car may not necessarily be wheeled and may not necessarily move horizontally? Such assumptions would definitely increase both efficiency and distance of travel, especially if car is lifted vertically.

- Maximizing efficiency means that many parameters need to optimized at once, to find a global maximim for a function of several variables. What are these parameters?

- Which of them are fixed by the task itself and which should be frozen for coherence of experiments, but which can be tuned? (size, aerodynamic shape, type and brand of the balloon? gas, possibly not only air, used as a "fuel"? sizes, masses, friction factors of gears, wheels, transmissions, suspensions and other mechanical parts? shape and size of the nozzle, if a "rocket car" concept is chosen? basic engineering concept behind the car?)

- Maximizing efficiency and maximizing the distance of travel is not one and the same thing. How to clarify and deeply investigate the topic?

- How to establish the definition and determine the efficiency for a balloon car? What total energy is stored in the inflated rubber membrane and in the compressed air?

- What are your basic conclusions on the problem?
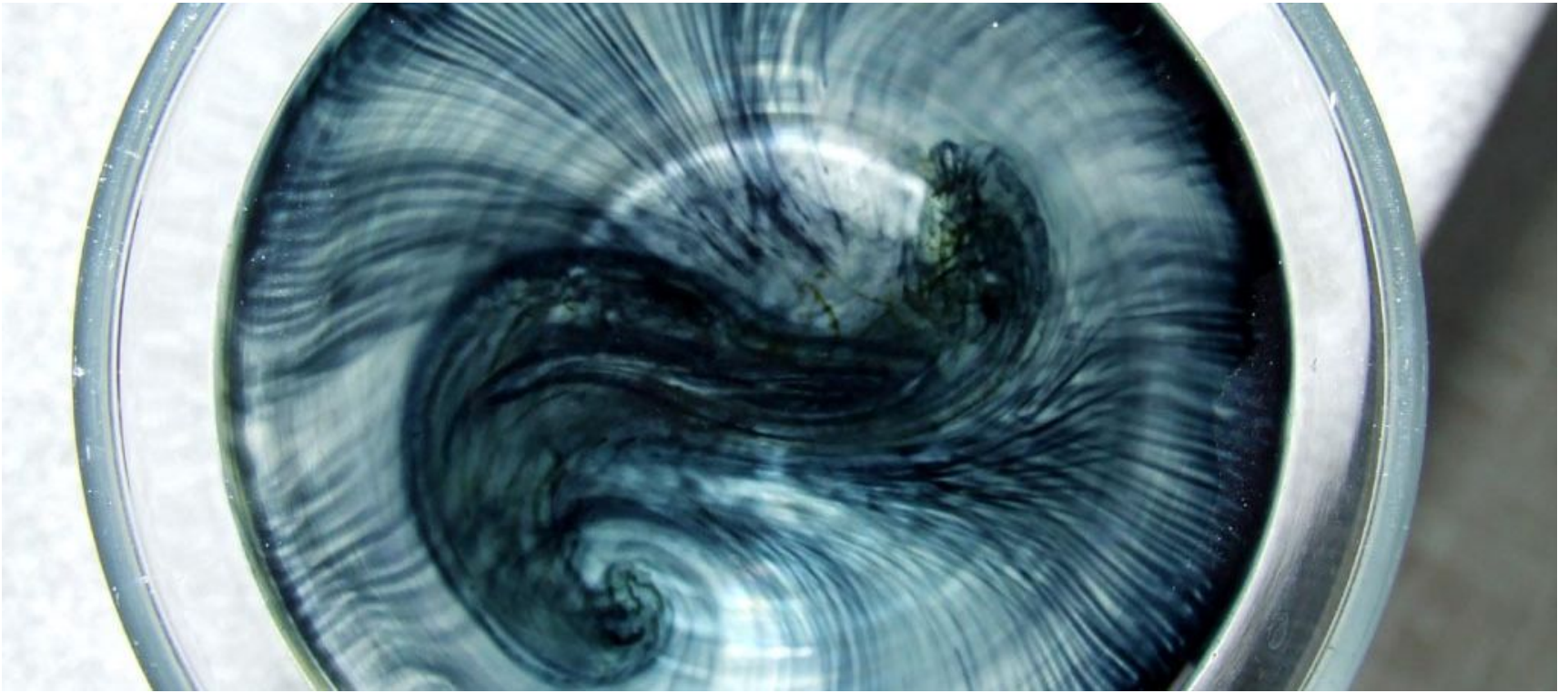
Problem No. 6 "Convection"

In a container filled with a liquid, heat transport will occur when the bottom of the container is heated and the top surface is cooled. How does the phenomenon change when the container rotates about its vertical axis?

IYPT history

- **13.** Heat transfer (1st IYPT, 1988)
  - Research the heat-transfer through the vertical water column in two cases: *T1<T2* and *T1>T2*. ("*1*" is water column, "*2*" is heat-insulating tube.)
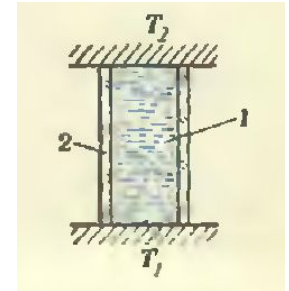
- **7.** Merry-go-round (13th IYPT, 2000)
  - A small, light, ball is kept at the bottom of a glass filled with an aqueous solution and then set free. Select the properties of the solution, so that a moving up time of several seconds is achieved. How will this time change if you put your glass on the surface of a rotating disk?

- **10.** Liquid fingers (13th IYPT, 2000)
  - When a layer of hot salt solution lies above a layer of cold water, the interface between the two layers becomes unstable and a structure resembling fingers develops in the fluid. Investigate and explain this phenomenon.

- **17.** Ocean "Solaris" (18th IYPT, 2005)
  - A transparent vessel is half-filled with saturated salt water solution and then fresh water is added with caution. A distinct boundary between these liquids is formed. Investigate its behaviour if the lower liquid is heated.

- **13.** Spinning ice (21st IYPT, 2008)
  - Pour very hot water into a cup and stir it so the water rotates slowly. Place a small ice cube at the centre of the rotating water. The ice cube will spin faster than the water around it. Investigate the parameters that influence the ice rotation.

Background reading

- Rayleigh-Bénard and Bénard-Marangoni convection (Experimental Nonlinear Physics Group, Dept. of Physics, University of Toronto), http://www.physics.utoronto.ca/~nonlin/thermal.html
- L. Kadanoff. Turbulent heat flow: structures and scaling. Physics Today 54, 34-39 (2001)
- Denis Funfschilling, Guenter Ahlers. Plume motion and large-scale circulation in a cylindrical Rayleigh-Bénard cell. Phys. Rev. Lett. 92, 194502 (2004), arXiv:nlin/0402039v1 [nlin.CD]
- J. Q. Zhong, R. J. A. M. Stevens, H. J. H. Clercx, R. Verzicco, D. Lohse, and G. Ahlers. Prandtl-, Rayleigh-, and Rossby-number dependence of heat transport in turbulent rotating Rayleigh-Benard convection. Phys. Rev. Lett. 102, 044502 (2009), http://www.nls.physics.ucsb.edu/papers/ZSCVLA08_PRL.pdf
- J. W. Portegies, R. P. J. Kunnen, J. Molenaar, and G. J. F. van Heijst. A model for vortical plumes in rotating convection. Phys. Fluids, 20, 6, 066602-1-10 (2008)
- R. P. J. Kunnen, H. J. H. Clercx, and B. J. Geurts. Breakdown of large-scale circulation in turbulent rotating convection. Europhys. Lett. 84, 2, 24001-1-6 (2008)
- R. P. J. Kunnen, H. J. H. Clercx, B. J. Geurts. Enhanced vertical inhomogeneity in turbulent rotating convection, Phys. Rev. Lett., 101(17), 174501-1-4 (2008)
- R. P. J. Kunnen, H.J.H. Clercx, B. J. Geurts, L. J. A. van Bokhoven, R. A. D. Akkermans, R. Verzicco. Numerical and experimental investigation of structure function scaling in turbulent Rayleigh-Bénard convection, Phys. Rev. E, 77(1), 016302-1-13, (2008)
- R. P. J. Kunnen, H. J. H. Clercx, B. J. Geurts, Heat flux intensification by vortical flow localization in rotating convection, Phys. Rev. E, 74(5), 056306-1-4 (2006)

Background reading

- R. J. A. M. Stevens, H. J. H Clercx, D. Lohse. Effect of weak rotation on boundary layers and heat transfer, submitted to Europhys. Lett. (2008)
- J.Q. Zhong, R.J.A.M. Stevens, H.J.H. Clercx, R. Verzicco, D. Lohse, and G. Ahlers, Prandtl-, Rayleigh-, and Rossby-number dependence of heat transport in turbulent rotating Rayleigh-Benard convection, Phys. Rev. Lett. 102, 044502(2009)
- Transitions between turbulent states in rotating Rayleigh-Benard convection, by Richard Stevens, Jin-Qiang Zhong, Herman Clercx, Guenter Ahlers and Detlef Lohse, Phys. Rev. Lett. 103, 024503 (2009).
- Turbulent rotating convection (Eindhoven University of Technology), http://web.phys.tue.nl/nl/de_faculteit/capaciteitsgroepen/transportfysica/fluid_dynamics_lab/turbulence_vortex_dynamics/rotating_rayleigh_benard_convection/
- A. E. Mikelsons. Vortex structures in a rotating fluid. Geophys. & Astrophys. Fluid Dyn. 74, 1-4, 135-142 (1994)
- J. E. Hart. On the influence of centrifugal buoyancy on rotating convection. J. Fluid Mech. 403, 133-151 (2000)
- Ilya Martchenko. A ball lifts in a rotating vessel: observations and explanation. Proc. Physics and Progress 2007 (St Petersburg State University, November 14-16, 2007), p. 149
- М. Ван-Дайк. Альбом течений жидкости и газа. — М.: Мир, 1986

Key questions

- Is the problem all about axisymmetrical vessels? What internal velocity fields (transitory and stationary) are developed when the vessel is rotated? What physical properties of the vessel are relevant? (depth? shape?)

- How relevant are the parameters of heating? (all bottom is heated uniformly, or not?) What are the roles of temperature gradients or heat fluxes?

- Aside from density, what other parameters of liquid change with heating (viscosity?) Is there an interface "tension" between miscible layers of different temperatures? Can we neglect the change of momentum, or inertial forces, for the heated flows?

- What models or concepts may be introduced to describe the time scales for the flows of positive buoyancy and the rotational displacement? Is it physically correct to say that upward convection may be considered "slower" or "faster" than rotation? As there is an interplay and superposition between the two phenomena, can they be analyzed independently?

- What are the values and the physical sense for the dimensionless criteria relevant to the effect?

- Is there a way to separate particular miscible flows? How to visualize experimentally the overall flow lines?

- Can the observed convection patterns be structured into physically different types?

Problem No. 7 "Cup drum"

A plastic cup is held upside-down and tapped on its base. Investigate the sound produced when the open end of the cup is above, on or below a water surface.

IYPT history

- **6.** Singing glass (12th IYPT, 1999)
  - When rubbing the rim of a glass containing a liquid a tone can be heard. The same happens if the glass is immersed in a liquid. How does the pitch of the tone depend on different parameters.
- **9.** Flute (21st IYPT, 2008)
  - Drill a hole into the side of a tube that is open at one end and produce a sound by blowing the open end. Investigate the pitch and timbre of the sound of your flute and how they depend on the position and the diameter of the hole.

Background reading

- Lord Rayleigh. The Theory of Sound. (London, Macmillan, 1877, Courier Dover Publications, 1945), http://books.google.com/books?id=v4NSAlsTwnQC, http://books.google.com/books?id=Frvgu1wSFfUC

- N. H. Fletcher and T. D. Rossing. The Physics of Musical Instruments. (New York, Springer-Verlag, 1991), http://books.google.com/books?id=9CRSRYQlRLkC

- Superposition and standing waves. In: Raymond A. Serway, John W. Jewett. Physics for Scientists and Engineers (2004), http://www.electron.rmutphysics.com/physics/charud/scibook/Physics-for-Scientists-and-Engineers-Serway-Beichne%206edr-4/18%20-%20Superposition%20and%20Standing%20Waves.pdf

- Élise Lorenceau, David Quéré, Jean-Yves Ollitrault, and Christophe Clanet. Gravitational oscillations of a liquid column in a pipe. Phys. Fluids, 14, 6, 1985-1992 (2002), http://www.pmmh.espci.fr/fr/gouttes/Publications_files/Gravitational%20oscillations.pdf

- Jin-Meng Ho. Ray acoustics and vibration of immersed thin elastic cylindrical shells excited by an on-surface source. Wave Motion, 22, 1, 75-96 (1995)

- G. I. Taylor. An experimental study of standing waves. Proc. R. Soc. London 218, 44 (1953)

- Standing Air Waves; Resonance (University of Nevada, Reno), http://physics.unr.edu/180labs/Old%20Standing%20Air%20Waves.pdf

- J. D. Murphy, E. D. Breitenbach, H. Überall. Resonance scattering of acoustic waves from cylindrical shells. J. Acoust. Soc. Am. 64, 677-683 (1978)

- P. Pareige, G. Maze et J. Ripoche. Résonances d'un tube élastique : source d'émission acoustique interne. Revue Phys. Appl. 22, 83-88 (1987), http://hal.archives-ouvertes.fr/docs/00/24/55/19/PDF/ajp-rphysap_1987_22_1_83_0.pdf

- Open *vs* Closed pipes (University of New South Wales), http://www.phys.unsw.edu.au/jw/flutes.v.clarinets.html

Key questions

- What are the key differences between a cup (a cylinder open at one end) and a cylinder open at both ends? What changes when the mouth of the cup is immersed in water? What determines the positions of nodes and antinodes for the cup in question?
- What physical properties of the cup are relevant? (volume, shape, height, radius of curvature? spatial orientation? material and thickness of the walls? elastic properties, such as compressibility?)
- Are there any standing waves in the air column inside the cup? What do the amplitudes and frequencies of the standing waves depend on?
- What parameters describe the sound produced by the cup? Which of them are "physical" and which are "subjective"? (timber? tone color? volume? pitch?)
- What properties of the air change when it is compressed by the water column? How exactly they depend on the immersion depth? What physical properties of the water and basin are relevant (density? compressibility? depth in a given point?)
- What are the spectra of the produced sounds? Do they change with time? After the initial excitation, how is the energy re-distributed among various oscillatory modes? Are any resonance effects relevant to this phenomenon? It is correct to speak of a fundamental frequency for the oscillations? What is an acoustic impedance and what is its influence on the produced sound?
- It seems to be reasonable to record the tube's sound. What should be the requirements for the sound-recording equipment? Where to place the microphone? What is the sound inside the cup?
- What total acoustic energy is produced by the oscillating cup? How does it correspond to the energy of tapping?

Problem No. 8 "Domino amplifier"

A row of dominoes falling in sequence after the first is displaced is a well known phenomenon. If a row of "dominoes" gradually increases in height, investigate how the energy transfer takes place and determine any limitations to the size of the dominoes.

IYPT history

- **8.** Dominoes (6th IYPT, 1993)
  - Dominoes are placed vertically at a small distance from each other in a long row on a table surface. Make the first domino fall and the "wave of the falls" will proceed along the row. Calculate and measure experimentally the maximum speed of this wave.

θ_∞ is the angle at which the dominoes are stacked against each other at the end of the train. We call θ_∞ the stacking angle.
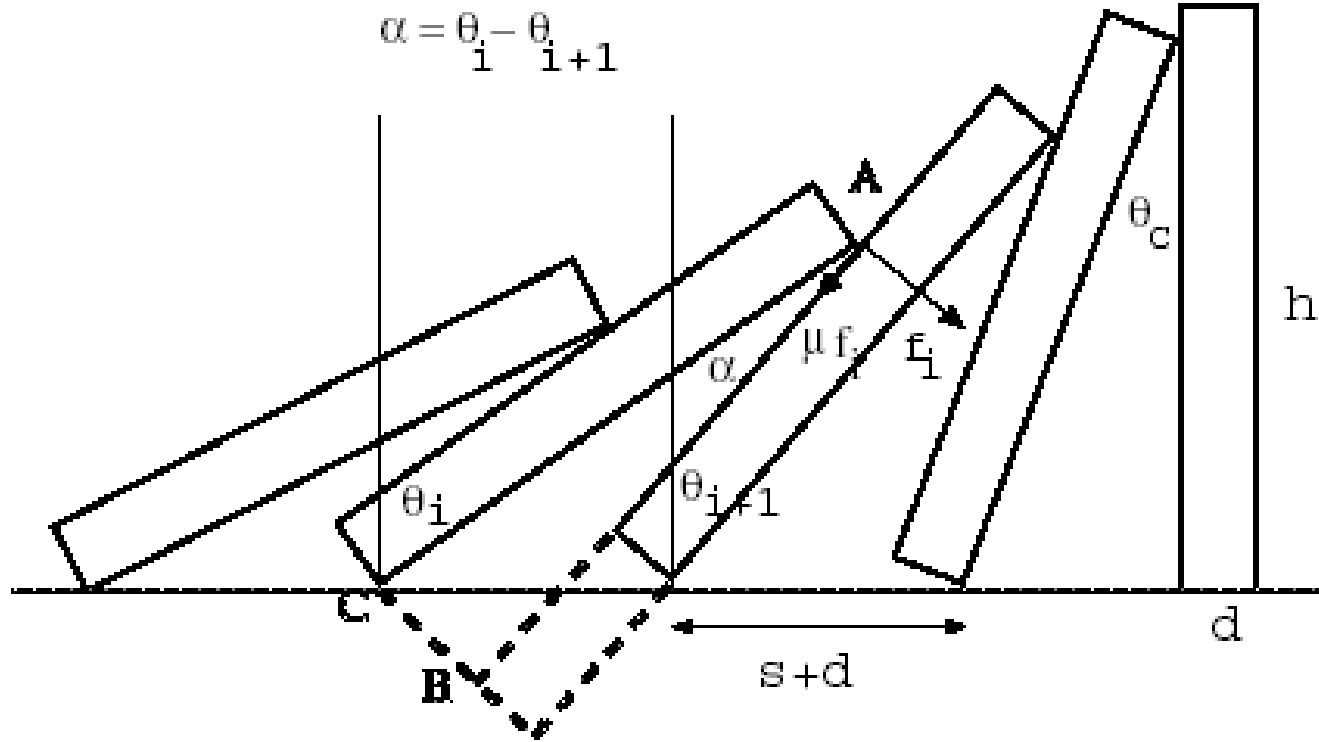

Figure 1: Successive dominoes. The tilt angle θ_i is taken with respect to the vertical. In the rectangular traingle ABC the top angle is $\alpha = \theta_i - \theta_{i+1}$, the hypotenuse has the length h and the base BC the length $(s + d)\cos\theta_{i+1} - d$. Expressing this base in the hypotenuse and the top angle yields relation (1). In the picture the tilt angle of the head of chain θ_n has reached its final value $\theta_c = \arcsin(s/h)$. The first domino has almost reached the stacking angle θ_∞. The normal force f_i and the friction force μf_i that domino i exerts on $i + 1$ are also indicated.

Background reading

- Wikipedia: Domino effect, http://en.wikipedia.org/wiki/Domino_effect
- J. M. J. van Leeuwen. The domino effect. Am. J. Phys. 78, 7, 721-727 (2010), arXiv:physics/0401018v1 [physics.gen-ph]
- W. J. Stronge. The domino effect: a wave of destabilizing collisions in a periodic array. Proc. R. Soc. Lond. A 409, 199-208 (1987)
- W. J. Stronge and D. Shu. The domino effect: Successive destabilisation by cooperative neighbours. Proc. R. Soc. Lond. A 418, 1854, 155-163 (1988)
- J. Walker. The Amateur Scientist: deep think on dominoes falling in a row and leaning out from the edge of a table. Scientific American (Aug. 1984)
- C. J. Efthimiou, M. D. Johnson. Domino waves. SIAM Review 49, 1, 111-120 (2007), arXiv:0707.2618v1 [math.DS]
- Ron Larham. Validation of a model of the domino effect? arXiv:0803.2898v1 [math.HO]
- Robert B. Banks. Towing icebergs, falling dominoes, and other adventures in applied mathematics (Princeton University Press, 1998)
- D. E. Shaw. Mechanics of a chain of dominoes. Am. J. Phys. 46, 6, 640-642 (1978)
- Ron Larham. Measuring the speed of the domino effect using the Windows Sound Recorder, Part 1. Citizen Scientist (Nov. 2007), www.sas.org/tcs/weeklyIssues_2007/2007-11-02/project2/index.html
- Ron Larham. Measuring the speed of the domino effect using the Windows Sound Recorder, Part 2. Citizen Scientist (Dec. 2007), www.sas.org/tcs/weeklyIssues_2007/2007-12-07/project2/index.html

Background reading

- J. K. Freericks. http://www.physics.georgetown.edu~jkf/class mech/demo1.ps.
- B. G. MacLachlan, G. Beaupre, A. B. Cox, and L. Gore. Falling dominoes. SIAM Review 25, 3, 403-404 (1983)
- J. C. Kimball, H.L. Frisch. Random walks, avalanches and branching processes. arXiv:cond-mat/0606454v1 [cond-mat.stat-mech]
- C. W. Bert. Falling dominoes. SIAM Review 28, 2, 219-224 (1986)
- Tad McGeer and Leigh Hunt Palmer. Wobbling, toppling, and forces of contact. Am. J. Phys. 57, 12, 1089-1098 (1989)
- C. Clanet. Dominoes race. Submitted to Am. J. of Phys. (2003)
- Steve Koellhoffer, Chana Kuhns, Karen Tsang, and Mike Zeitz. Falling dominoes (University of Delaware, December 9, 2005), http://www.math.udel.edu/~rossi/Math512/2005/Team3.pdf

Key questions

- How valid is an assumption that a wave of dominoes is a sequence of physically similar cycles of interactions between two (or a finite number) of dominoes?
- The exact procedure of initial "excitation" may certainly influence on the dynamics of the first dominoes in the row. Is the system "forgetting" initial conditions, and if so, when it happens?
- What parameters may be safely neglected (slipping? air resistance?) and which may not?
- If a theory is proposed, can it be used to describe not only individual collisions, but the system as a whole? Is your theory capable of predicting certain parameters, or retrieving information about other parameters through fitting experimental dependences? Is it worth modelling the system numerically?
- The height of individual dominoes may be growing linearly with number, but may also not. Can the problem be understood from a point of view that dominoes are identical, but their height (or, spatial position) increases, i.e. dominoes are on a staircase (vertical dominoes) or an inclined plane (tilted dominoes)? How to formalize and fix the initial approach to the problem?
- What parameters of the substrate are relevant? How does the dynamics of the wave depend on these parameters?
- What parameters of dominoes themselves are relevant (sizes and law of growth in height? friction factors?) How relevant is the step between dominoes, and it grow or decrease in the row?
- How to measure, tune, and control all necessary parameters in the experiments? Are the sizes and the ultimate speed of the wave the only major parameters?
- Above all, what happens to potential, kinetic translational, kinetic rotational, and other energies for individual dominoes and for a system as a whole? How the energy is actually transferred? What are the criteria for a particular domino to withstand, or not, when hit by a neighbor?

[Michiel Thomas 2007]

Problem No. 9 "Escaping powder"

When a hot wire is plunged into a beaker of water with powder (e.g. lycopodium) floating on the surface, the powder moves rapidly. Investigate the parameters that alter the speed of movement of the powder.

IYPT history

- **4.** Dusty blot (17th IYPT, 2004)

  - Describe and explain the dynamics of the patterns you observe when some dry dust (e.g. coffee powder or flour) is poured onto a water surface. Study the dependence of the observed phenomena on the relevant parameters.

- **5.** Razor blade (20th IYPT, 2007)

  - A razor blade is placed gently on a water surface. A charged body brought near the razor makes it move away. Describe the motion of the razor if an external electric field is applied.

- **9.** Ink droplet (20th IYPT, 2007)

  - Place a droplet of ball pen ink on a water surface. The droplet begins to move. Explain the phenomenon. Describe and explain the dynamics of the patterns you observe when some dry dust (e.g. coffee powder or flour) is poured onto a water surface. Study the dependence of the observed phenomena on the relevant parameters.

What changes in the system when we immerse the hot wire?

- Temperature and Surface Tension (Ask a Scientist, 2004), http://www.newton.dep.anl.gov/askasci/gen01/gen01725.htm
- Surface Tension (Georgia State University), http://hyperphysics.phy-astr.gsu.edu/hbase/surten.html
- Abhishek Dasgupta, Shubham Dipt. Variation of surface tension with temperature (Indian Inst. Sci. Ed. Res.), http://www.abhidg.net/tension.pdf
- Experiment 446.1: Surface Tension of Liquids (University of Delaware, 2006), http://www.udel.edu/pchem/C446/Experiments/exp1.pdf

Surface tension is temperature dependent, but is it the only or the major factor?

Basic questions

- At least, several explanations may come to mind,
    - surface tension is temperature-sensitive; particles are repelled due to the different menisci, as the heating is not uniform…
    - oxide layer (hydrophilic) on the wire is being degraded; particles get repelled from a pure metal (hydrophobic) wall…
    - surface layer is being contaminated with surfactants from the wire, changing the surface tension and making the particles repelled…
- If you propose an explanation, does it look as a subject to direct experimental proof or disproof?
- What qualitative or quantitative experiments may be held to directly validate or invalidate your explanation? What is a "confirmability" and a "falsifiability" or a physical theory?

MOUVEMENTS SPONTANÉS

DE CERTAINS CORPS A LA SURFACE DE QUELQUES LIQUIDES

Le camphre, diverses substances solides odorantes, les corps poreux imbibés de liquides volatils, offrent à la surface de l'eau des mouvements singuliers de rotation et de translation, qui ont beaucoup préoccupé le monde savant dans la première moitié du siècle. On a voulu les attribuer tantôt à l'électricité, et tantôt à de simples phénomènes mécaniques de recul produits par le dégagement des vapeurs ou de parties fluides émanées du corps et venant frapper l'air ou l'eau; mais aucune solution définitive, aucune explication claire et satisfaisante n'a été donnée pour ces phénomènes.

Dutrochet, l'illustre auteur de la découverte de l'endosmose, après des études malheureusement entachées de graves erreurs à leur début (1841), mais aussi appuyées à la fin (1843) sur des expériences d'une haute valeur, ne trouva rien d'autre, pour expliquer les mouvements qui nous occupent, que l'existence hypothétique d'une force inconnue, apparaissant à la surface de séparation de deux liquides quelconques et qu'il nomma force épipolique (ἐπιπολῆ, surface). Cette notion d'une nouvelle force

quelconque est aussi le siège d'une force qui agit exactement comme si la masse liquide se terminait par une membrane très mince, élastique et tendue. On a reconnu que c'est à cette force que sont dus les phénomènes de la capillarité et peut-être bien d'autres moins connus: disons même, pour terminer ces notions succinctes, que cette *tension superficielle* des liquides n'est très probablement qu'un cas particulier de l'attraction qui s'exerce entre tous les corps.

Nous savons donc qu'il existe constamment à la surface de tous les liquides une force parfois puissante dans ses effets. Mais il e... que l'intensité de cette force c... du liquide considéré; on le re... un même tube capillaire dans... voit ceux-ci monter à des niv... Il suffit même de répandre une... liquide quelconque sur l'eau po... superficielle; presque toujours... une diminution, à cause de la t... l'eau à sa surface, supérieure... tous les autres liquides.

C'est guidé par ces notions th... de construire le petit jouet s... sur la figure (fig. 1). C'est un bateau taillé avec des

Background reading

- H.E. Devaux. Les lames très minces et leurs propriétés physiques. J. Phys. Radium 2, 8 237-272 (1931), http://hal.archives-ouvertes.fr/docs/00/23/30/66/PDF/ajp-jphysrad_1931_2_8_237_0.pdf

- H. Devaux. Mouvements spontanes de certains corps a la surface de quelques liquides. La Nature, 16, 777, 331-334 (1888), http://cnum.cnam.fr/PDF/cnum_4KY28.30.pdf

- Pushpendra Singha, Daniel D. Josephb, Sathish K. Gurupathama, Bhavin Dalala, and Sai Nudurupatia. Spontaneous dispersion of particles on liquid surfaces. PNAS 106, 47, 19761-19764 (2009)

- Victor W. Goldschmidt. Measurement of aerosol concentrations with a hot wire anemometer. J. Colloid Sci. 20, 6, 617-634 (1965)

- A. Marcelin. Solutions superficielles: fluides à deux dimensions et stratifications monomoleculaires (Les presses universitaires de France, 1933)

- H. Devaux. Ce qu'il suffit d'une souillure pour altérer la mouillabilité d'une surface. Étude sur le contact d'un liquide avec un solide. J. Phys. Radium 4, 9, 293-309 (1923), http://hal.archives-ouvertes.fr/docs/00/20/51/03/PDF/ajp-jphysrad_1923_4_9_293_0.pdf

- Henri Devaux. Sur l'épaisseur critique des solides et des liquides réduits en lames très minces. J. Phys. Theor. Appl. 3, 1, 450-453 (1904), http://hal.archives-ouvertes.fr/docs/00/24/09/09/PDF/ajp-jphystap_1904_3_450_1.pdf

- Ilya Martchenko. The qualitative study of Devaux's phenomenon. Abstr. Physics and Progress 2005 (St Petersburg State University, Nov. 1-3, 2005), p. M-07

- Marcos Gugliotti, Mauricio S. Baptista, Mario J. Politi, Todd P. Silverstein, Carl D. Slater. Surface tension gradients induced by temperature: The thermal Marangoni effect. J. Chem. Educ. 81, 6, 824 (2004)

Background reading

- D. Y. C. Chan, J. D. Henry, L. R. White. The interaction of colloidal particles collected at the fluid interface. J. Colloid Interface Sci. 79, 410–418 (1981)

- M. A. Fortes. Attraction and repulsion of floating particles. Can. J. Chem. 60, 2889–2895 (1982)

- K. Katoh, H. Fujita, E. Imazu. Motion of a particle floating on a liquid meniscus surface. J. Fluids Eng. 114, 411–417 (1992)

- M. M. Nicolson. The interaction between floating particles. Proc. Camb. Philos. Soc. 45, 288–295 (1949)

- H. M. Princen. In: Equilibrium shape of interfaces, drops and bubbles. Rigid and deformable particles at interfaces. Surface and Colloid Science (ed. E. Matijevic, Interscience, New York, 1969), 2, 1– 84

- A. V. Rapacchietta, A. W. Neumann. Force and free-energy analyses of small particles at fluid interfaces: II. Spheres. J. Colloid Interface Sci. 59, 555–567 (1977)

- P. Singh P and D. D. Joseph. Fluid dynamics of floating particles. J. Fluid Mech. 530, 31– 80 (2005), www.aem.umn.edu/people/faculty/joseph/archive/docs/350.pdf

- S. B. Pillapakkam. P. Singh. A Level Set Method for computing solutions to viscoelastic two-phase flow. J. Comput. Phys. 174, 552–578 (2001)

- P. Singh, T. I. Hesla, D. D. Joseph. A modified distributed Lagrange multiplier/Fictitious domain method for particulate flows with collisions. Int. J. Multiphas. Flow 29, 495–509 (2003)

- P. Singh, D. D. Joseph, T. I. Hesla, R. Glowinski, T. W. Pan. Adistributed Lagrange multiplier/fictitious domain method for viscoelastic particulate flows. J. Non-Newton Fluid 91, 165–188 (2000)

Background reading

- S. Osher and J. A. Sethian. Fronts propagating with curvature-dependent speed: Algorithms based on Hamilton-Jacobi formulations. J. Comput. Phys. 83, 12–49 (1988)

- Marcos Gugliotti. Response to Historical Scientific Literature and the Spreading of Oil on Water. J. Chem. Educ. 86 (7), 808 (2009)

- Todd P. Silverstein. Historical Scientific Literature and the Spreading of Oil on Water. J. Chem. Educ., 2009, 86 (7), p 807

- Daniel D. Joseph. Fluid Dynamics of Floating Particles. In: Interrogations of Direct Numerical Simulation of Solid-Liquid Flows (University of Minnesota, 2002), http://www.efluids.com/efluids/books/Interog-10.pdf

- W. H. Binder. Supramolecular assembly of nanoparticles at liquid-liquid interfaces. Angew. Chem. Int. Ed. 44, 5172–5175 (2005)

- K. Tsujii. Surface Activity: Principles, Phenomena, and Applications (Academic,

- San Diego, 1998)

- P. A. Cox. Hydrophilous pollination. Annu. Rev. Ecol. Syst. 19, 261–280 (1988)

- F. T. Short FT, Wyllie-Eciieverria S (1996) Natural and human-induced disturbance of seagrasses.

- Environ Conserv 23:17–27.

- W. T. Mitchella and J. A. Quinn. Convection induced by surface-tension gradients: experiments with a heated point source. Chem. Eng. Sci. 23, 5, 503-507 (1968)

- Agnes Pockels. Lettre à Lord Rayleigh dans Nature, 43 (1890), p. 437.

- A new secondary battery. The Electrician 5, 345 (1886)

- Golding Bird. Elements of natural philosophy (Churchill, 1839), p. 138

Background reading

- Solid markers, bubbles, and droplets. In: Stavros Tavoularis. Measurement in fluid mechanics (Cambridge University Press, 2005), p. 230

- R. J. Gummow and I. Sigalas. The thermal conductivity of talc as a function of pressure and temperature. International Journal of Thermophysics 9, 6, 1111-1120 (1988)

- E. K. Chapin. The strange world of surface film. Phys. Teach. 4, 271 (1966)

- Paul G. Jasien and Glenn Barnett. Lowering the surface tension of water: An illustration of the scientific method. J. Chem. Educ., 70, 251 (1993)

- Todd P. Silverstein. Cohesive and Adhesive Forces versus Surface Tension Gradients—Revisited. J. Chem. Educ. 81, 35 (2004)

- George B. Middlebrook and Edgar L. Piret. Hot wire anemometry: solution of some difficulties in measurement of low water velocities. Industrial Eng. Chem. 42, 8, 1511-1513 (1950)

- V. N. Paunov, P. A. Kralchevsky, N. D. Denkov, and K. Nagayama. Lateral capillary forces between floating submillimeter particles. J. Colloid Interface Sci. 157, 110-112 (1993), http://www.hull.ac.uk/scg/paunov/reprints/6.pdf

- P. A. Kralchevsky and K. D. Danov. Interactions between particles at a fluid interface. In: Nanoscience: Colloidal and Interfacial Aspects (Ed. V. M. Starov, CRC Press, New York, 2010), ch. 15, pp. 397-435, http://www.lcpe.uni-sofia.bg/publications/2010/2010-07-PK-KD-Particles-at-Fluid-Interface.pdf

- Lateral capillary forces between floating particles. In: Peter A. Kralchevsky and Kuniaki Nagayama. Particles at Fluid Interfaces and Membranes (Elsevier, 2001), http://books.google.com/books?id=Lsvn5zl7gvsC

Background reading

- Introducing the oil film experiment (practicalphysics.org, 2010),
  http://www.practicalphysics.org/go/Experiment_631.html
- David A. Katz. Determination of the size of a fatty acid molecule (chymist.com, 2004),
  http://www.chymist.com/size%20fatty%20acid.pdf
- Pepper Scatter (Surfing Scientist, abc.net.au),
  http://www.abc.net.au/science/surfingscientist/pepperscatter.htm
- Wikipedia: Lycopodium, http://en.wikipedia.org/wiki/Lycopodium
- T.R. Akylas. Lecture 4: Marangoni flows (MIT lecture notes), http://web.mit.edu/1.63/www/Lec-notes/Surfacetension/Lecture4.pdf
- Wikipedia: Marangoni effect, http://en.wikipedia.org/wiki/Marangoni_effect
- Kusuhiro Mukai, Taishi Matsushita, and Seshadri Seetharaman. Motion of fine particles in liquid caused by interfacial tension gradient in relation to metals separation technologies. Scandinavian J. Metallurgy 34, 2, 137–142 (2005)
- Simon Ostrach. Motion induced by surface-tension gradients. Bull. Mater. Sci. 4, 2, 125-132 (1982)
- D. D. Joseph, J. Wang, R. Bai, B. H. Yang, and H. H. Hu. Particle motion in a liquid film rimming the inside of a partially filled rotating cylinder. J. Fluid Mech. 496, 139-163 (2003),
  http://www.aem.umn.edu/Solid-Liquid_Flows/Documents/capillarity.pdf,
  http://repository.upenn.edu/cgi/viewcontent.cgi?article=1218&context=meam_papers
- Dave Ansell. Mysterious Movements - Surface Tension and a Ball (The Naked Scientists, 2010),
  http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/mysterious-movements-surface-tension-and-a-ball/

Key questions

- Above all, what types of motion can be observed?

- What is a hot-wire anemometer, and is it relevant to the problem?

- Why do floating particles attract or repulse, and how does the effect depend on their contact angles with liquid, on surface tension, and on other parameters?

- How is the heat transferred from the wire into the liquid? If the wire is initially heated, how does the temperature field in the beaker evolve with time? What changes, if the wire is being heated by electric current when already immersed? What parameters (initial temperature, heat conductivities, specific heat capacities) are relevant?

- How does the surface tension depend on temperature? What other parameters of water change with temperature (viscosity, density,…?)

- Does the oxide on the metal wire effectively withstand heating and immersion? How to check this aspect?

- Do particles move before the wire is immersed? Is the motion after immersing wire connected to overcoming viscous drag? Singh *et al.* explain the cause for constant-temperature repulsion not only by unbalanced capillary forces due to unequal contact angles, but also by vertical oscillations of particles. Is there a way to investigate deeper into the topic, and provide visual and straightforward experimental evidence for what happens?

- What are the speeds, accelerations, and directions of particles' motion? How to record and analyze them? How do they depend on multiple relevant parameters, such as the temperature gradient?

- What physical information can be retrieved if two hot wires are immersed? Is the observed motion consistent with the (assumed) superposition of interactions? Are the observed accelerations indeed the vector sums only?

- Does your explanation permit a direct experimental proof or disproof? If surface tension is considered changing, is it possible to measure it via generating capillary waves or other techniques?

- It maybe uneasy to buy lycopodium in a local pharmacy. What parameters of lycopodium particles are important, and what replacement (a model system) may be appropriate? What parameters need to be kept under control? (wettability? mass? mean size and shape?)

- Is it possible to measure the lateral forces acting on particles? Is there a room for Brownian motion?
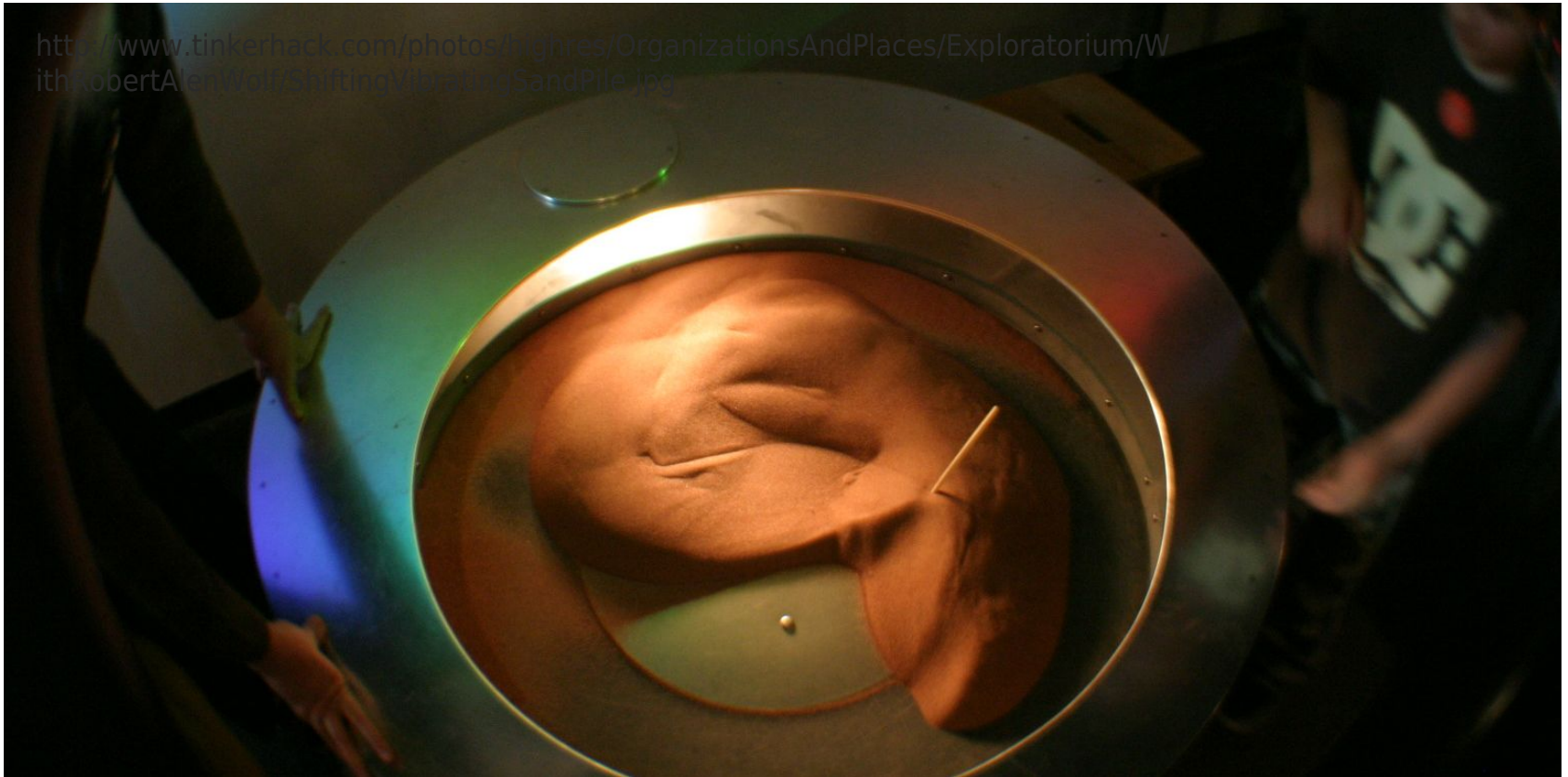
Problem No. 10 "Faraday heaping"

When a container filled with small spheres (e.g. mustard seeds) is vibrated vertically with a frequency between 1 – 10 Hz, so called Faraday heaping occurs. Explore this phenomenon.

XVII. *On a peculiar class of Acoustical Figures; and on certain Forms assumed by groups of particles upon vibrating elastic Surfaces.* By M. FARADAY, *F.R.S. M.R.I., Corr. Mem. Royal Acad. Sciences of Paris, &c. &c.*

Read May 12, 1831.

1. THE beautiful series of forms assumed by sand, filings, or other grains, when lying upon vibrating plates, discovered and developed by CHLADNI, are so striking as to be recalled to the minds of those who have seen them by the slightest reference. They indicate the quiescent parts of the plates, and visibly figure out what are called the nodal lines.

2. Afterwards M. CHLADNI observed that shavings from the ha[...] citing violin bow did not proceed to the nodal lines, but were gath[...] on those parts of the plate the most violently agitated, i. e. at t[...] oscillation. Thus when a square plate of glass held horizontall[...] above and below at the centre, and made to vibrate by the ap[...] violin bow to the middle of one edge, so as to produce the lo[...] sound, sand sprinkled on the plate assumed the form of a di[...] but the light shavings were gathered together at those parts towar[...] of the four portions where the vibrations were most powerful a[...] sions of the plate greatest.

3. Many other substances exhibited the same appearance. Lycopodium,

Chladni figures →
nice, but is it relevant to the problem?
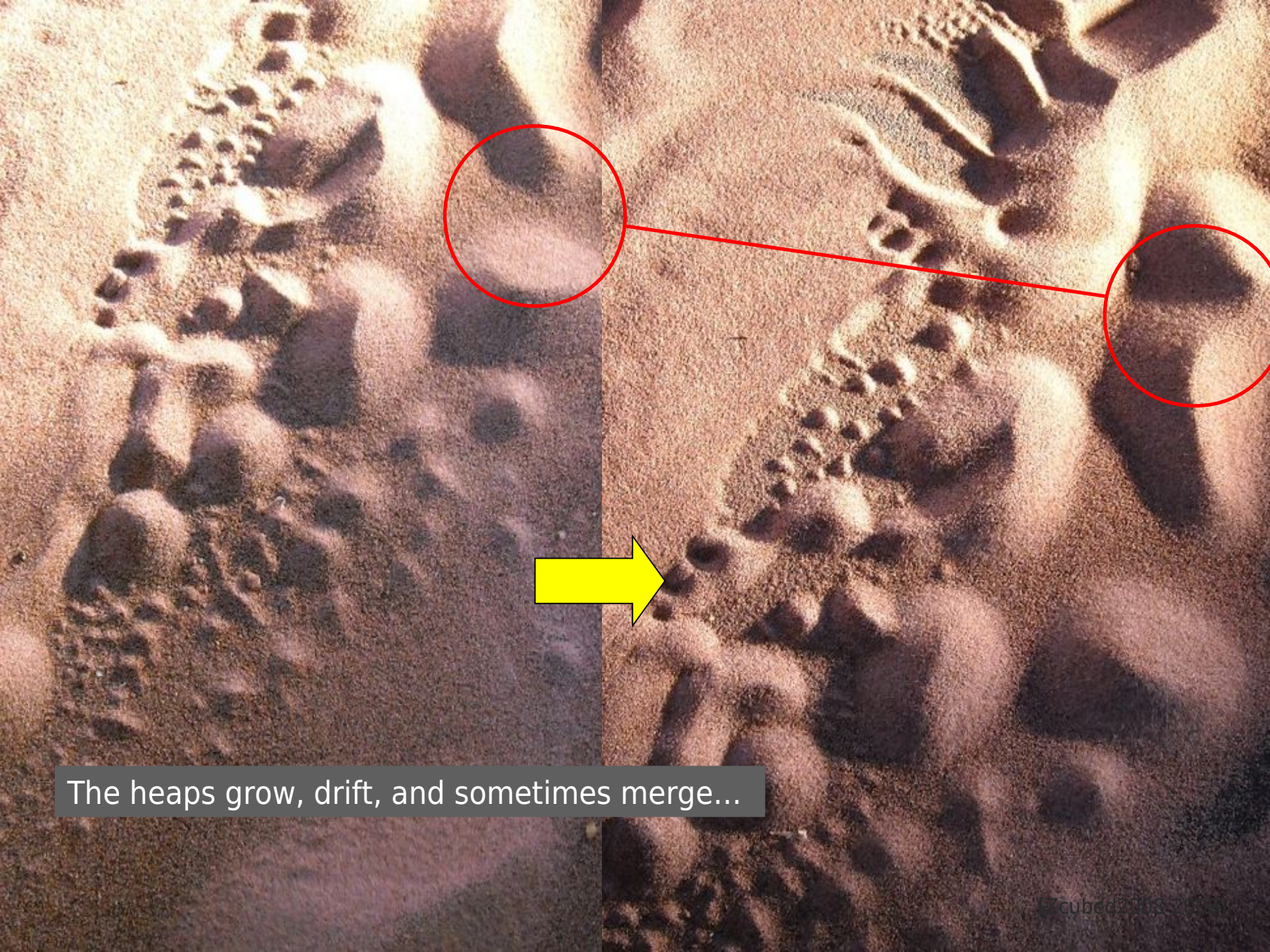
Heaps and ripples appear on many different length scales…

Granules are not closely packed. Can we safely neglect the air involved?
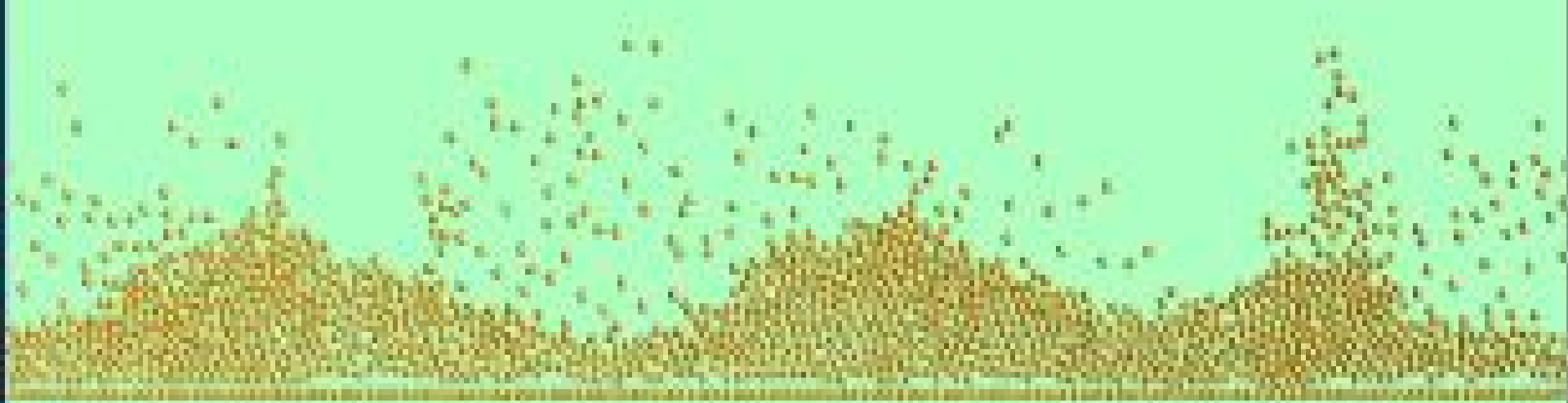
The heaps grow, drift, and sometimes merge...

How does the overall pattern depend on the parameters of shaking?

http://www.ph.biu.ac.il/~rapaport/anim_gif/vibgran_anim.gif

spontaneous pattern formation in a dynamical system outside of equilibrium [4].

The dynamic stabilization of a single heap (last snapshot of Fig. 1) is well understood: The outward avalanches in the upper layers are balanced by the inward motion of the deeper layers (induced by the airflow through the vibrating bed [2,3]), together forming the convective flow of particles known as Faraday circulation. By contrast, the merging of small heaps into larger ones—the coarsening process (Fig. 1)—is much less understood, and quantitative experiments have been scarce [5,6].

In the present study we introduce a model for the coarsening behavior, validated by experiments and detailed numerical simulations. This threefold approach leads to the identification of the average life span τ_N of the N-heap state as the proper coarsening quantity. It is proven to scale, in our 1D setup, as $\tau_N \propto N^{-3}$.

Experiments.—A glass box of dimensions $L \times H \times D = 300 \times 100 \times 2.1$ mm^3 is vertically vibrated using a

proce

t = 0.00 s

t = 1.44 s

t = 6.56 s

t = 13.12 s

t = 16.32 s

t = 33.44 s

t = 96.32 s

t = 122.72 s

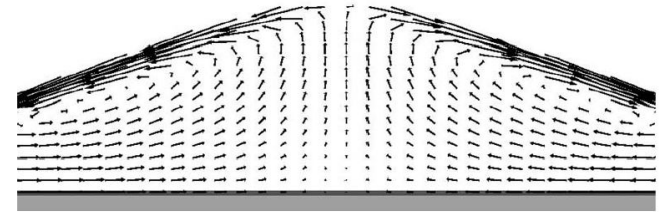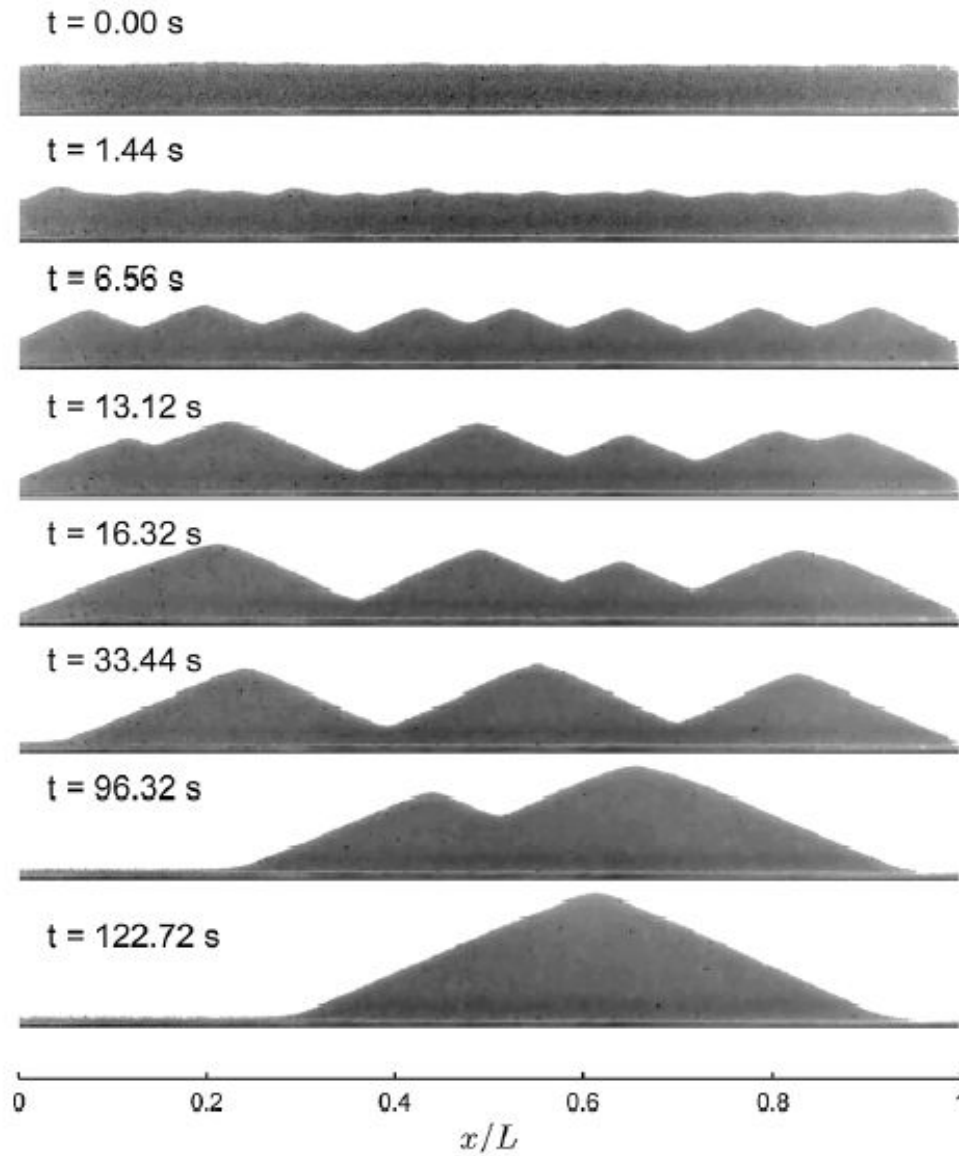0   0.2   0.4   0.6   0.8   1

x/L

FIG. 2. Circulation in the Faraday heap: The arrows indicate the particle displacement (multiplied by 2 for clarity) during one driving cycle, averaged over 25 cycles. The part of the heap shown here corresponds to the black box in Fig. 1.

[van Gerner *et al.* 2007]

[van Gerner *et al.* 2009]

FIG. 1. Coarsening of a vertically vibrated 1D granular bed, as recorded in our experiments. It takes roughly two minutes to evolve from a flat landscape to a single Faraday heap. Every image is taken at the same point during the vibration cycle, when the container moves upward and the bed is pressed against the floor.

Interactions in granular medium

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ϕ_{t+dt}

Kinetic

ϕ_t

Collisional & Kinetic

ϕ_t

ϕ_{t+dt}
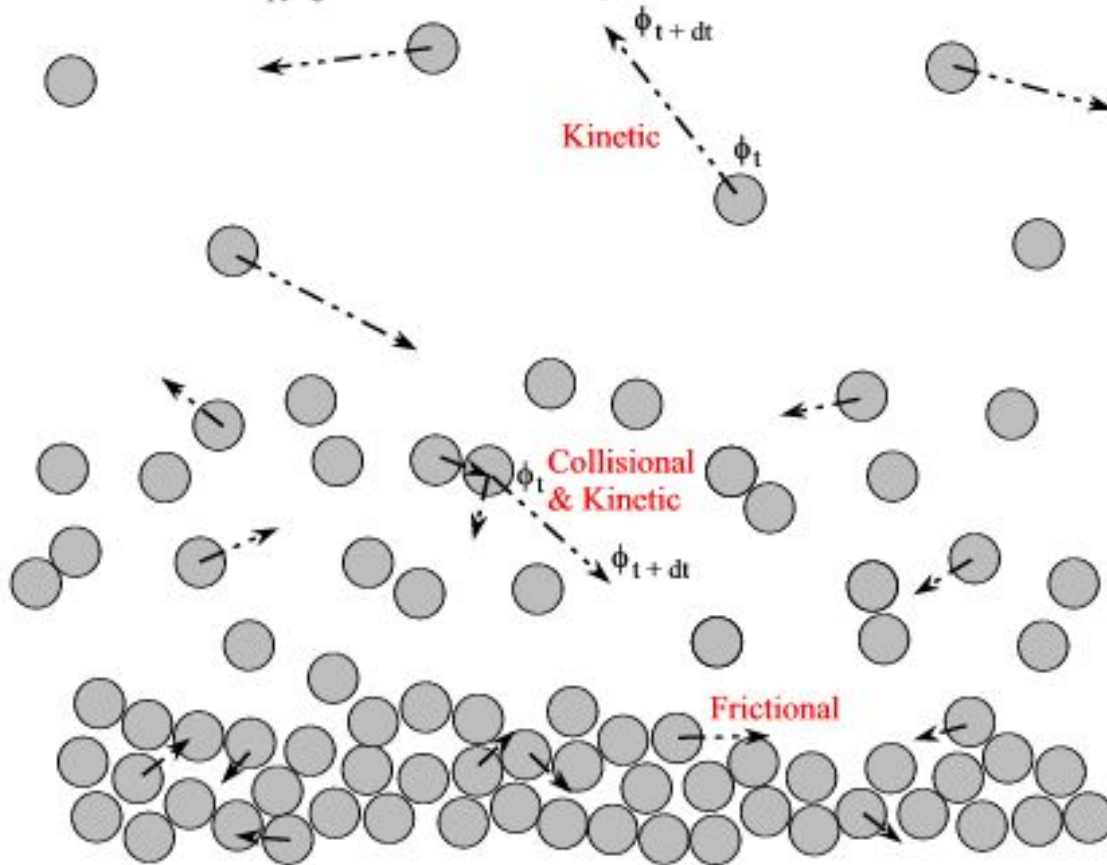
Frictional

kinetic → dilute part of the flow, grains randomly translate; viscous dissipation and stress

collisional → higher concentration, grains also collide shortly; collisional dissipation and stress

frictional → very high concentration (>50% volume fraction), grains endure long, sliding and rubbing contacts

Earlier research...

[van Gerner *et al.* 2007]
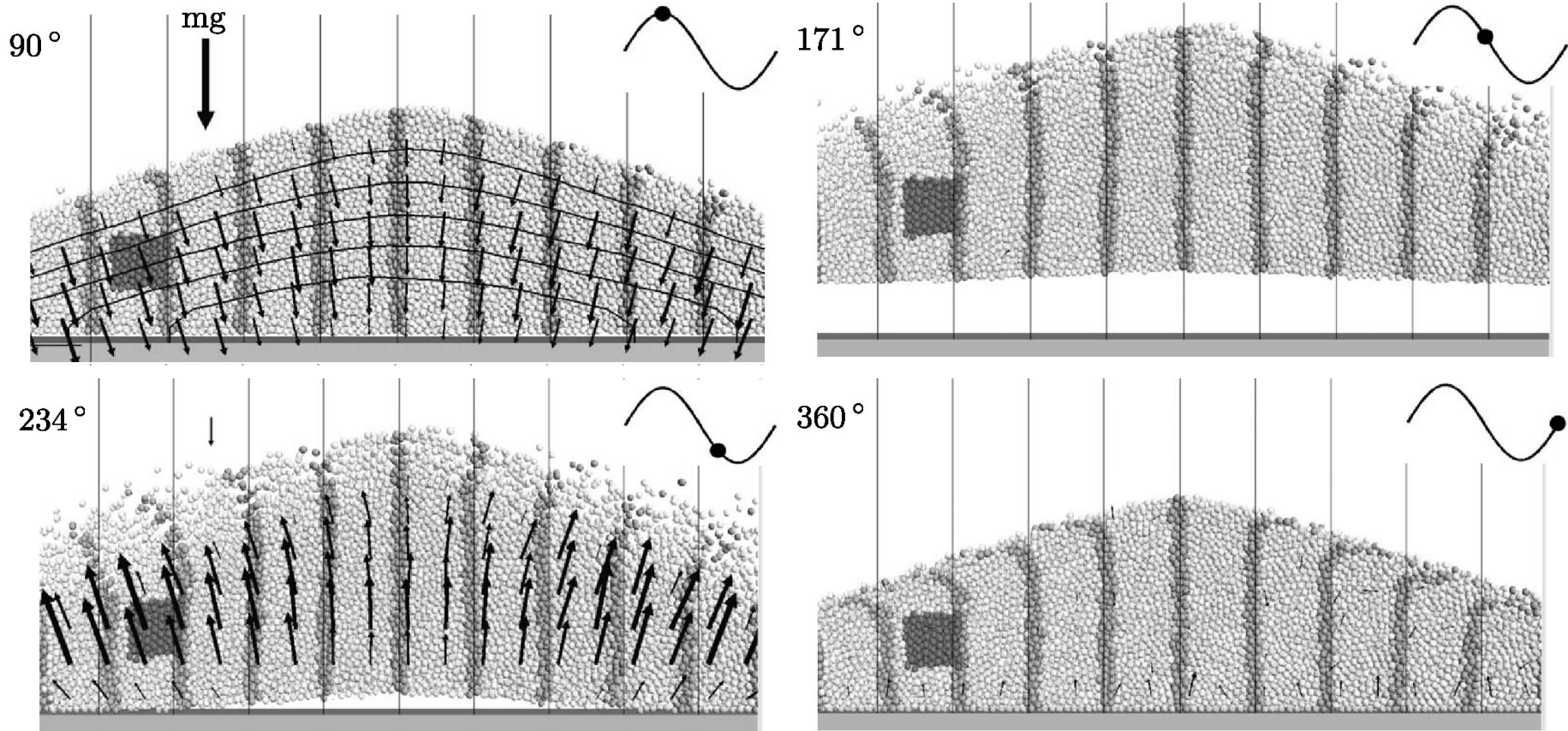
Stokesian forces (drag, air pressure) → drive particles towards the center?
Newtonian forces (from collisions and gravity) → drive particles outward?

IYPT history

- **4.** Self-formation of a pile (9th IYPT, 1996)
  - A horizontal rigid plate vibrates vertically at a frequency of the order of 100 Hz. A cone-shaped pile of fine dispersed powder (e.g. Licopodium or talc) which is heaped up on the plate remains stable at small amplitudes of the vibration. If the amplitude is increased the cone decays. Further increase of the amplitude yields a distribution confined by a sharp border and at still higher amplitudes a pile appears again. Investigate and explain this phenomenon.

- **16.** Coloured sand (13th IYPT, 2000)
  - Allow a mixture of differently coloured, granular materials to trickle into a transparent, narrow container. The materials build up in distinct bands. Investigate and explain this phenomenon.

- **7.** Oscillating box (16th IYPT, 2003)
  - Take a box and divide it into a number of small cells with low walls. Distribute some small steel balls between the cells. When the box is made to oscillate vertically, the balls occasionally jump from one cell to another. Depending on the frequency and the amplitude of the oscillation, the distribution of the balls can become stable or unstable. Study this effect and use a model to explain it.

- **15.** Brazil Nut Effect (17th IYPT, 2004)
  - When a granular mixture is shaken the larger particles may end up above the smaller ones. Investigate and explain this phenomenon. Under what conditions can the opposite distribution be obtained?

How to visualize velocities and trajectories?
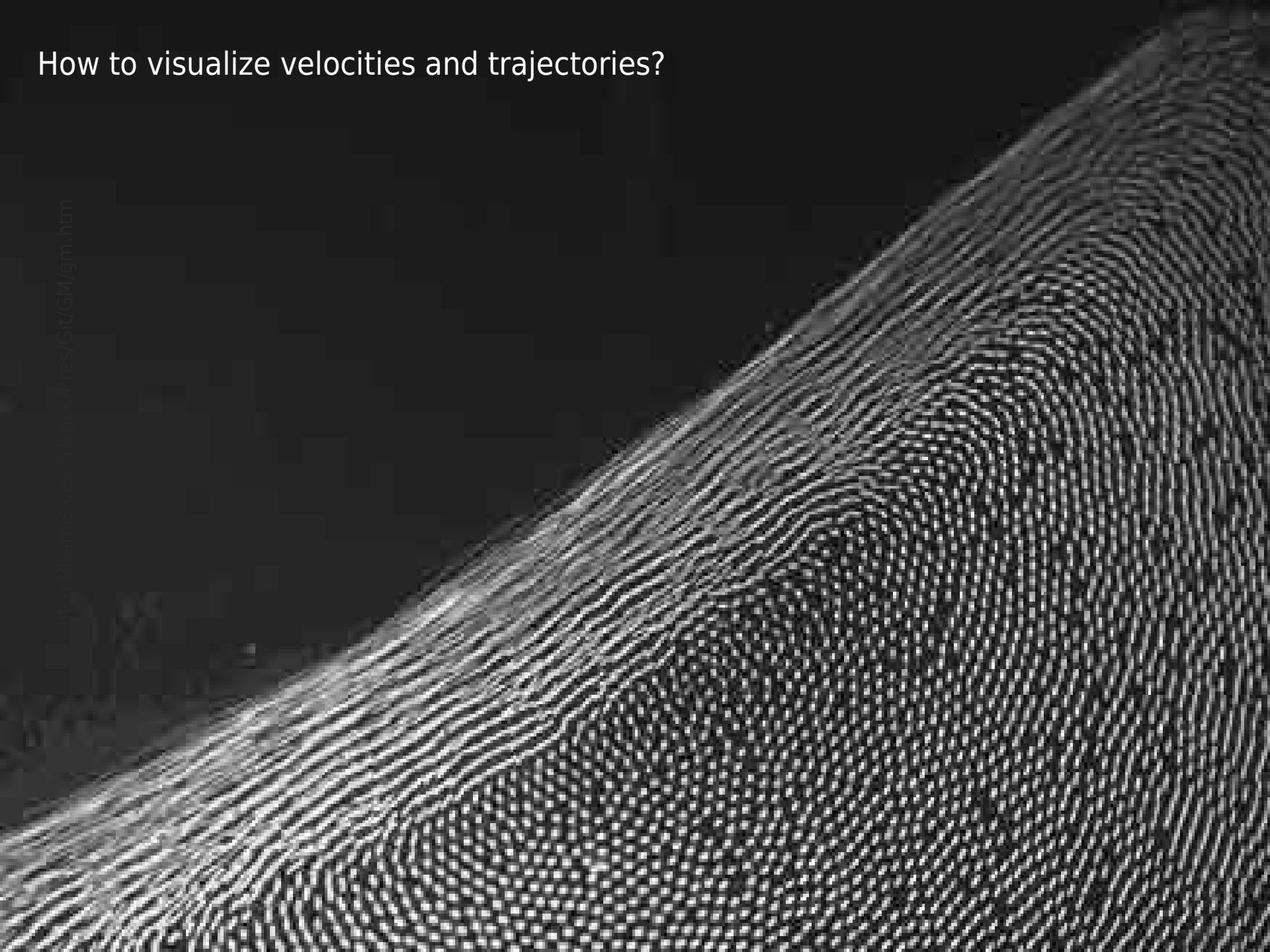
Background reading

- M. Faraday. On a peculiar class of acoustical figures; and on certain forms assumed by groups of particles upon vibrating elastic surfaces. Phil. Trans. R. Soc. London 121, 299-340 (1831)
- C. Laroche, S. Douady, and S. Fauve. Convective flow of granular masses under vertical vibrations. J. Phys. (Paris) 50, 699-706 (1989)
- S. Douady, S. Fauve, and C. Laroche. Subharmonic instabilities and defects in a granular layer under vertical vibrations. Europhys. Lett. 8 (7), 621-627 (1989)
- Ko van der Weele. Faraday heaping: the interplay of air and sand (University of Patras), http://www.math.upatras.gr/~weele/weelerecentresearch_FaradayHeaping.htm
- Newton vs Stokes: Competing Forces in Granular Matter (University of Twente), http://pof.tnw.utwente.nl/3_research/3_g_newtonstokes.html
- H. J. van Gerner, M. van der Hoef, D. van der Meer, and K. van der Weele. Interplay of air and sand: Faraday heaping unravelled. Phys. Rev. E 76, 051305 (2007), http://doc.utwente.nl/58270/1/interplay_of_air_and_sand.pdf
- H. J. van Gerner, G. A. Caballero Robledo, D. van der Meer, K. van der Weele, and M. A. van der Hoef. Coarsening of Faraday heaps: Experiment, simulation, and theory. Phys. Rev. Lett. 103, 028001 (2009), http://doc.utwente.nl/67345/1/coarsening.pdf
- R. L. Brown and J. C. Richards. Principles of powder mechanics (Pergamon Press, Oxford, 1970)
- Jysoo Lee. Heap formation in granular media. J. Phys. A 27, L257-L262 (1994), arXiv:cond-mat/9301004v1
- Guoqing Miao, Kai Huang, Yi Yun, Peng Zhang, Weizhong Chen, Xinlong Wang, Rongjue Wei. Formation and transportation of sand-heap in an inclined and vertically vibrated container. Phys. Rev. E 74, 021304 (2006), arXiv:cond-mat/0511693v1 [cond-mat.soft]

Background reading

- Hisao Hayakawa, Daniel C. Hong. Two hydrodynamic models of granular convection. Phys. Rev. Lett. 75, 2328 (1995), arXiv:cond-mat/9703086v1 [cond-mat.mtrl-sci]
- Francisco Melo, Paul Umbanhowar, Harry L. Swinney. Hexagons, kinks and disorder in oscillated granular layers. Phys. Rev. Lett. 75, 3838–3841 (1995), arXiv:patt-sol/9507003v1
- S. Luding, E. Clément, J. Rajchenbach, and J. Duran. Simulations of pattern formation in vibrated granular media. Europhys. Lett. 36, 247 (1996), arXiv:cond-mat/9606201v2
- A. Kudrolli. Size separation in vibrated granular matter. Rep. on Progr. Phys. 67, 3, 209-247 (2004), arXiv:cond-mat/0402205v1 [cond-mat.soft]
- Igor S. Aranson, Lev S. Tsimring. Patterns and collective behavior in granular media: Theoretical concepts. arXiv:cond-mat/0507419v1 [cond-mat.soft]
- Vibrating sand table (from wysz, May 30, 2009, youtube), http://www.youtube.com/watch?v=oDkQCfdRld8
- Zhang Hua, Wang Qi, and Miao GuoQing. Chinese Science Bulletin 53, 1, 12-16 (2008)
- D. C. Rapaport. Subharmonic surface waves in vibrated granular media. Physica A 249, 232 (1998), http://www.ph.biu.ac.il/~rapaport/papers/98b-phsa.pdf
- R. J. Milburn, M. A. Naylor, A. J. Smith, M. C. Leaper, K. Good, Michael R. Swift, and P. J. King. Faraday tilting of water-immersed granular beds. Phys. Rev. E 71, 011308 (2005)
- H. K. Pak, E. Van Doorn, and R. P. Behringer. Effects of ambient gases on granular materials under vertical vibration. Phys. Rev. Lett. 74, 23, 4643-4646 (1995), http://vortex.phys.pusan.ac.kr/publication/87-97/PRL04643.pdf
- Heinrich M. Jaeger, Sidney R. Nagel, and Robert P. Behringer. Granular solids, liquids, and gases. Rev. Mod. Phys. 68, 4, 1259-1273 (1996), http://jfi.uchicago.edu/~jaeger/group/JaegerGroupPapers/granular/Granular_RMP.pdf

Open questions

- Theory may require advanced tensor analysis :-/
  - but maybe it is possible to simplify everything with a rough, but clear theoretical approach? :-)
- Numerical simulations can help a lot
- What about making experiments and developing a theory for a 2D case? (grains are limited by two parallel glass plates)
- Visualizing the motion and structure of heaps can be very helpful!
  - playing with exposure time for still images?
  - using colored grains?
  - making clear, informative videos (slow-motion?)
- How far the heaps are reproducible, if everything is repeated? When does the system "forgets" initial conditions? Why?
- How about reading more about relevant concepts from granular or soft matter physics, such as percolation, close packing, dynamic arrest?

Key questions

- Above all, what is the cause of the phenomenon?
- Does the phenomenon appear with different granular materials (sand...)?
- Why the frequency is proposed to be limited by 1-10 Hz? What happens at lower or higher amplitudes, and is it still possible to observe the effect with different grains?
- What parameters of the granular particles determine the shape of heaps? (density? particle shape? average particle size?) Do particles need to be monodisperse?
- How relevant are the properties of air (density? viscosity?)
- What are the relevant parameters during the shaking
  - amplitude, frequency, sine/non-sine oscillations?
- Is there a way to describe the 3D shape of heaps?
- How exactly does the wave pattern evolve in time?
- The heaps on initially almost plane layer. What is the maximum possible amplitude of the heaps?
- How to model such a phenomenon experimentally? What are the basic requirements for the equipment?
- Above all, what is your conclusion on the effect?
- What new we can add to this profoundly researched problem?

Problem No. 11 "Fingerprints"

Fill a glass with a liquid and hold it in your hands. If you look from above at the inner walls of the glass, you will notice that the only thing visible through the walls is a very bright and clear image of patterns on your fingertips. Study and explain this phenomenon.

What is the approximate gap between the skin and the glass for the raised epidermal ridges, and for the grooves between them?

Why the light is reflected from a "transparent" glass surface?

Transmitter or detector?
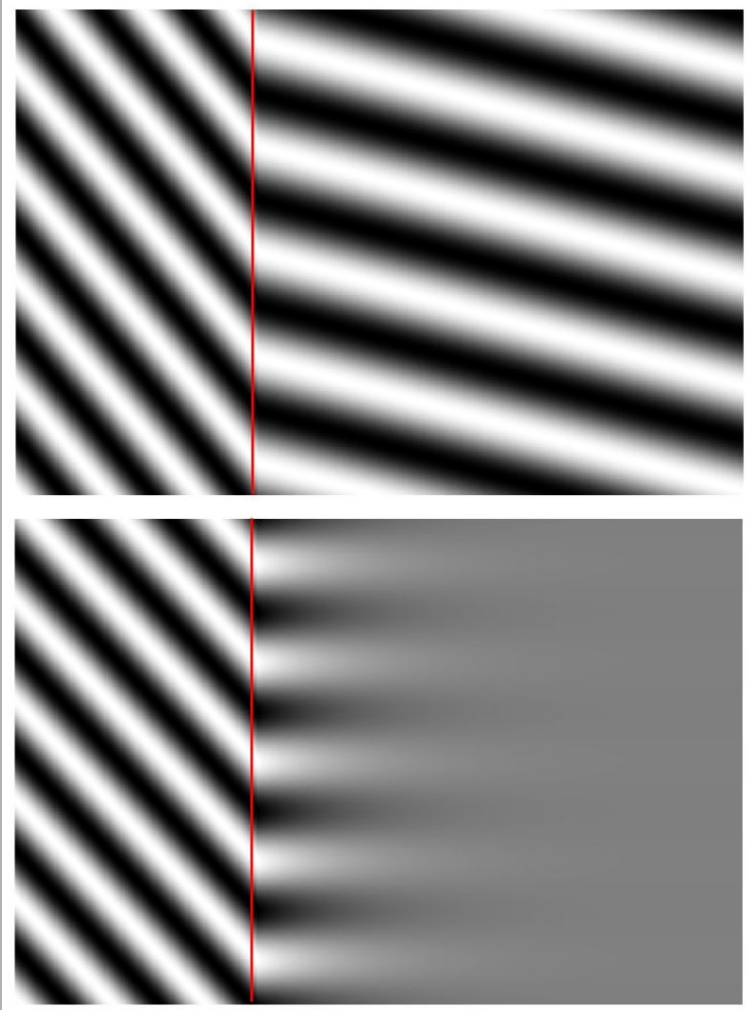
- Yes, a weak, exponentially decaying wave exists behind the interface at the distances comparable to a single wavelength :-)
- → Why?

Hey! Your eyes are not a light source, and your fingers are not your eyes

The optical information is transmitted from, not into the "evanescent wave" zone

The fingers are also neither a laser pointer, nor a light bulb :-)

- How to correctly describe the system?

Such demonstrations may tell a story about reflections and refractions, but how relevant they are to the problem?

Is the effect at all related to rays coming from behind of the glass?

What radiation, or optical information, is emitted, scattered or absorbed by the fingers, if any?

What is actually "visible" from these angles?

How does the visible image depend on the observation angle, shape of the glass, thickness of the walls and the properties of the liquid?

Laser pointer

Glass with water

An unexpected reflection can send the beam straight into the eye. Light power below 1...5 mW is unpleasant, but comparably safe; higher powers may cause retinal injuries and should never be used.
Stefan Wyrsch, Philipp B. Baenninger, Martin K. Schmid. Retinal injuries from a handheld laser pointer. N. Engl. J. Med. 363, 1089-1091 (2010)
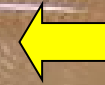
[Hiddenpower 2007]
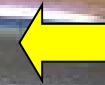
No liquid: objects behind are visible, displaced due to refraction

Liquid, but sufficient angle: objects behind are still visible, but gradually disappear as angle grows

Only fingerprints are visible

What is the ratio between visible "intensities" of fingers and the totally reflected images of surroundings?
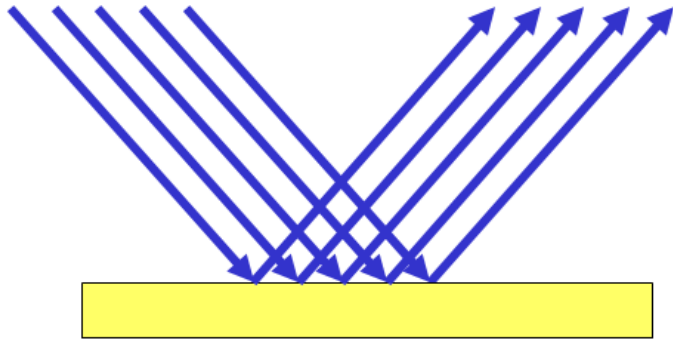Why the fingers appear darker?
Why the image seen from the rest of glass walls is so diffuse?

Would we see a laser pointing "into the camera"? (bright, directed light source?)
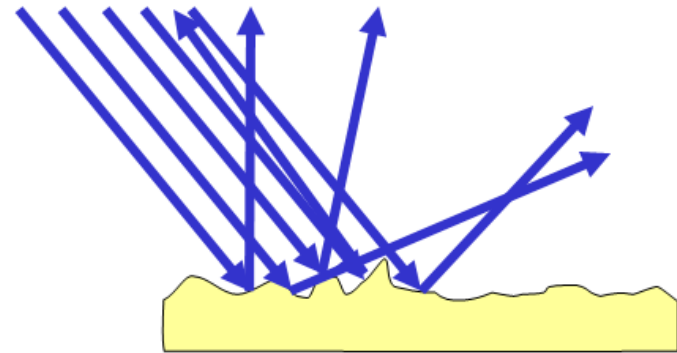
Would we see a dry napkin, a metal foil sheet, or even very dry fingers?
(what does it mean?)
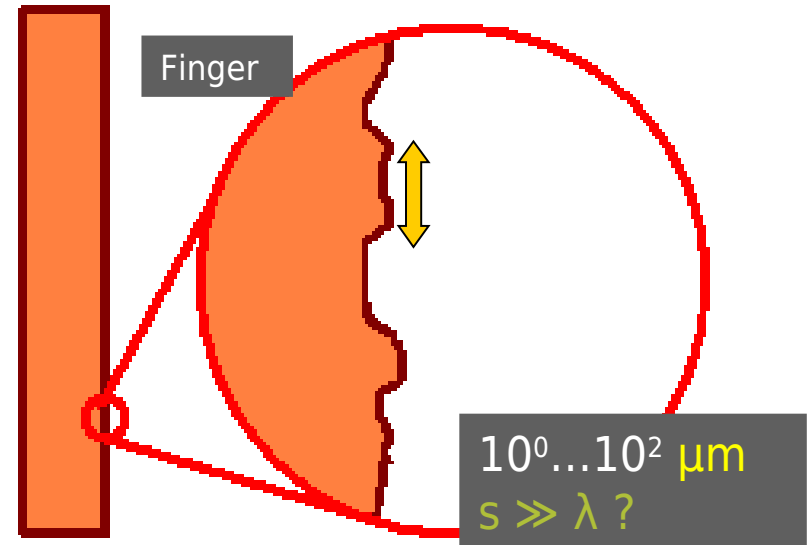
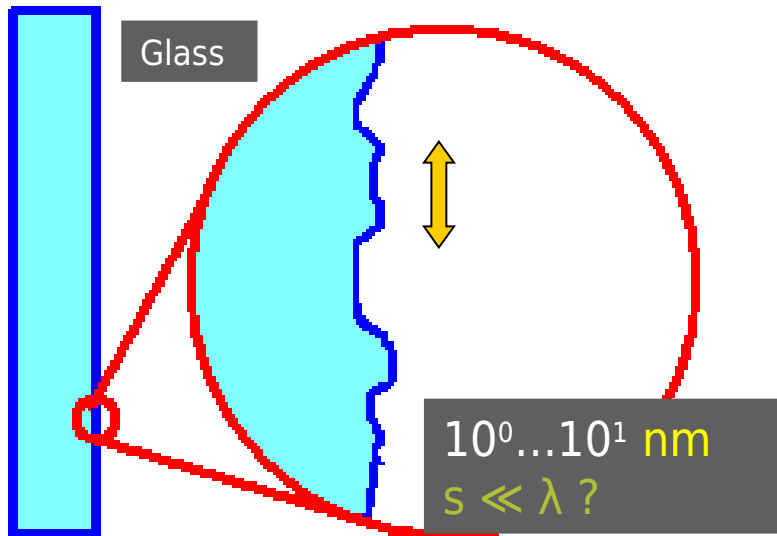# (Very) basic concepts

Specular Reflection

Diffuse Reflection

What is the role, if there are any, of light absorption by fingers?

How rough is the World?

Glass
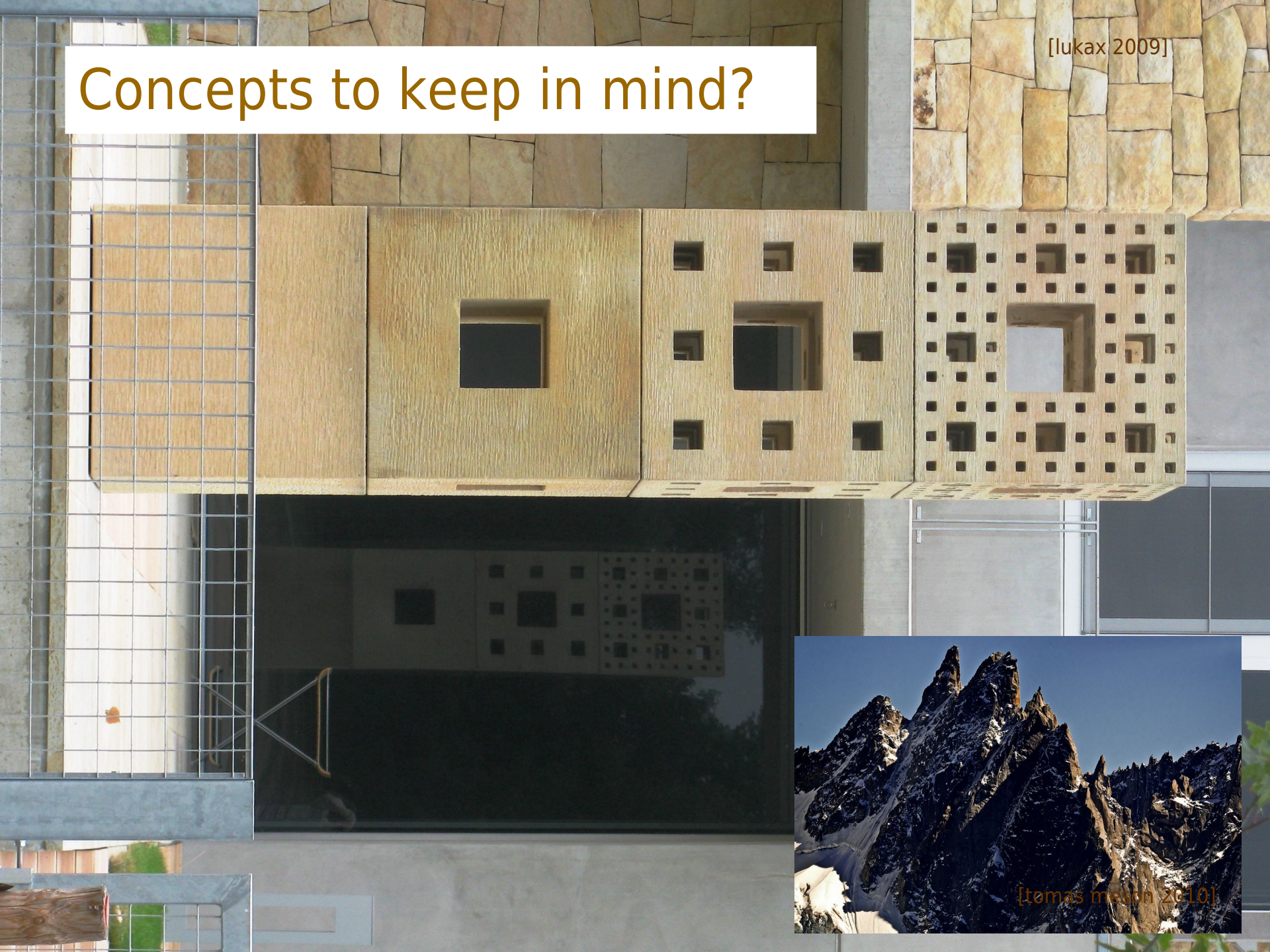
Finger

$10^0...10^1$ nm

$s \ll \lambda$?

$10^0...10^2$ μm

$s \gg \lambda$?

- Is it clear and evident why:
  - rough glass looks turbid?
  - rough surfaces do not work as mirrors?
  - rough surfaces scatter light?

[Daydream Designs 2010]

Concepts to keep in mind?
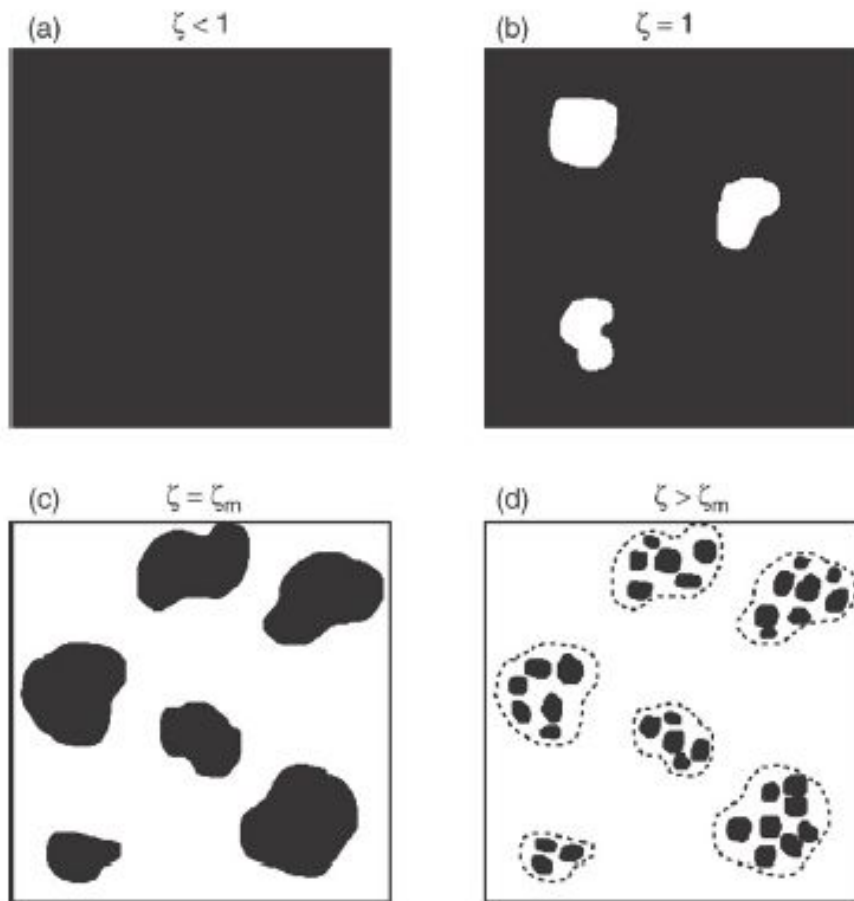
[lukax 2009]

[tomas medÿn 2010]

Contact area?

Fig. 12. The contact area at increasing magnification (a)–(d). The macroasperity contact area (c) breaks up into smaller contact areas (d) as the magnification is increased.
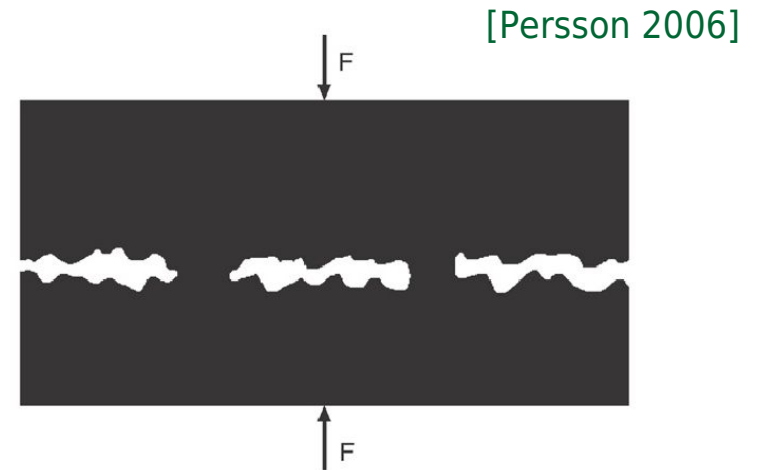

Fig. 1. Two solid blocks squeezed in contact with the force F. The area of real (atomic) contact A is usually an extremely small fraction of the nominal (or apparent) contact area A_0.

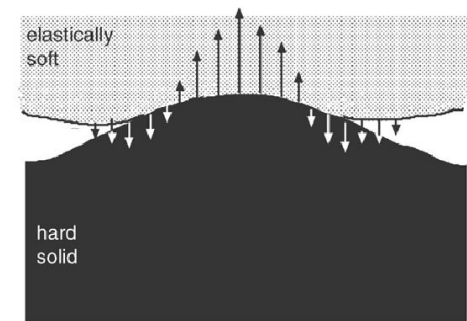Fig. 17. The stress distribution in an asperity contact region. The stress is tensile close to the boundary line of the contact area. An attractive wall–wall interaction occurs also outside the area of real contact and this interaction determines the detachment stress σ_a and the work of adhesion γ.
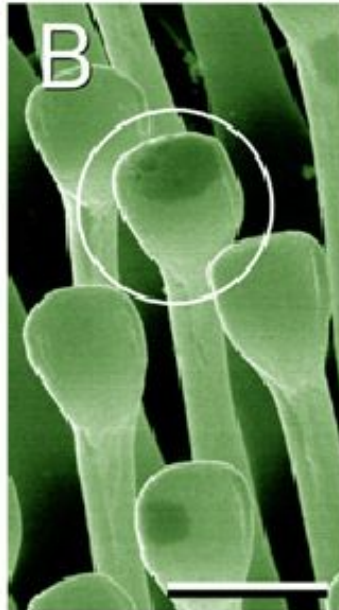
Off-the-point remark :-)

body mass ⟶

| A | B | C | D |
beetle   fly   spider   gecko

2 µm
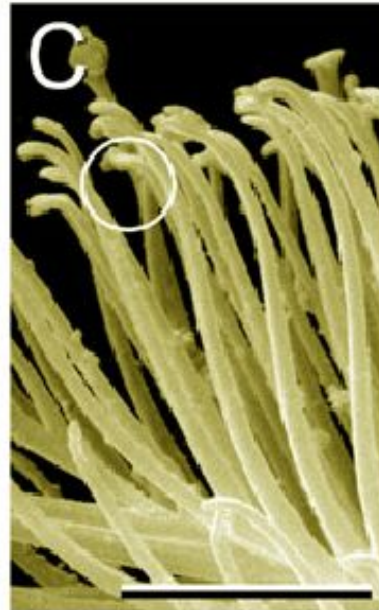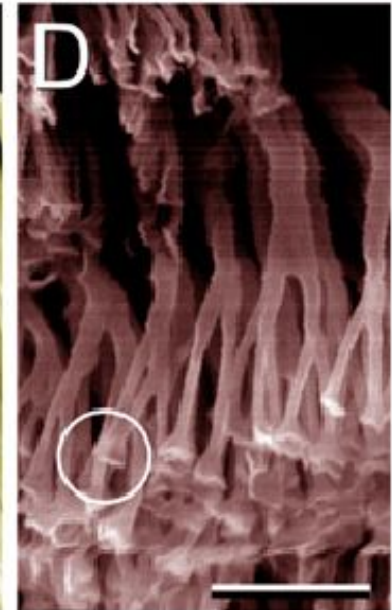
What touches glass?
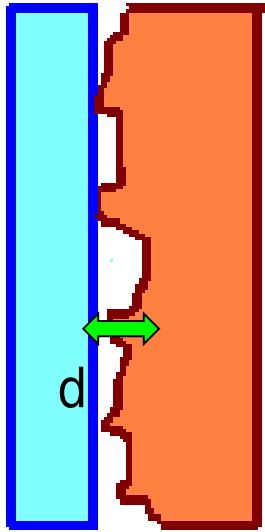
$d \ll \lambda \rightarrow$ direct glass-finger interface?

Do the fingers stick to the glass through molecular adherence?
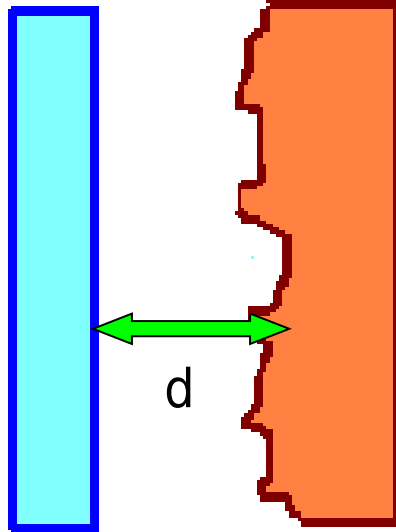
$d \gtrsim \lambda \rightarrow$ air gap?

Frustrated total internal reflection, optical tunelling?
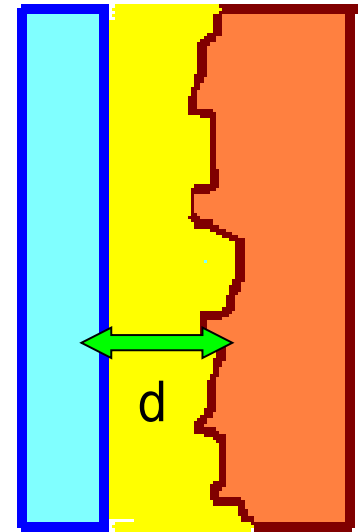
water/grease fills the gap between "raised ridges" and glass?

Direct glass-liquid and liquid-finger interfaces?

- washed and dry hands vs greasy and/or wet hands?
- liquid on fingers scatters or works as immersion fluid or both or none correct?
- are fingerprints visible when fingers are removed? (whatever yes or no, what does the result mean?)

Does grease scatter light?

[Pink Sherbet Photography 2009]

[Wolax 2009]

http://creativebits.org/files/images/dont_touch.png

IYPT history

- **2.** Light guide (3rd YPT, Correspondence Competition, 1981)
  - The properties of light guides are well illustrated by a glass or a plexiglas rod, bent e.g. as shown in the picture. Study the properties of a similar, or a more interesting, light guide made in the school laboratory. Construct a device illustrating or using the properties of a light guide.
- **15.** Optical tunneling (18th IYPT, 2005)
  - Take two glass prisms separated by a small gap. Investigate under what conditions light incident at angles greater than the critical angle is not totally internally reflected.
- **8.** Liquid light guide (23rd IYPT, 2010)
  - A transparent vessel is filled with a liquid (e.g. water). A jet flows out of the vessel. A light source is placed so that a horizontal beam enters the liquid jet (see picture). Under what conditions does the jet operate like a light guide?

Glass prism

Glass

s

IYPT
The International Young Physicists' Tournament
The Physics World Cup
Proceedings of the 18th IYPT 2005
14-21 July 2005, Winterthur, Switzerland

Problem No. 8 "Liquid light guide"
A transparent vessel is filled with a liquid (e.g. water). A jet flows out of the vessel. A light source is placed so that a horizontal beam enters the liquid jet (see picture). Under what conditions does the jet operate like a light guide?
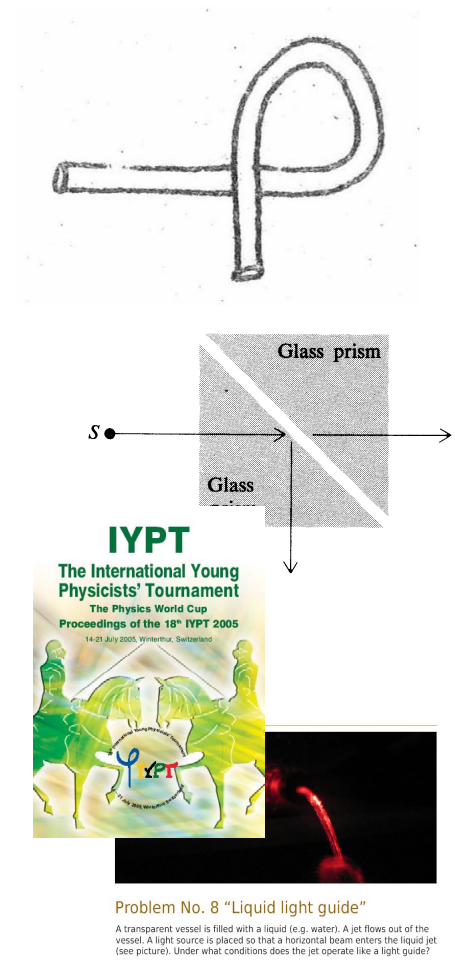
Background reading

- Wikipedia: Total internal reflection, http://en.wikipedia.org/wiki/Total_internal_reflection
- Wikipedia: Evanescent wave, http://en.wikipedia.org/wiki/Evanescent_wave
- Wikipedia: Quantum tunneling, http://en.wikipedia.org/wiki/Quantum_tunneling
- B. N. J. Persson, S. Gorb. The effect of surface roughness on the adhesion of elastic plates with application to biological systems. J. Chem. Phys. 119, 21, 11437-11444 (2003), http://juwel.fz-juelich.de:8080/dspace/bitstream/2128/1367/1/38088.pdf
- B. N. J. Persson. Contact mechanics for randomly rough surfaces. Surface Sci. Rep. 61, 201-227 (2006), http://www.multiscaleconsulting.com/resources/Contact+mechanics+for+randomly+rough+surface.pdf
- Evanescent Waves (Carnegie Mellon University), http://www.andrew.cmu.edu/user/dcprieve/Evanescent%20waves.htm
- E. E. Hall. The penetration of totally refected light into the rarer medium. Phys. Rev. 15,73-106 (1902)
- D. D. Coon. Counting photons in the optical barrier penetration experiment. Am. J. Phys. 34, 240-243 (1965)
- J. C. Castro. Optical barrier penetration: A simple experimental arrangement. Am. J. Phys. 43, 107-108 (1974)
- A. I. Mahan and C. V. Bitterli. Total internal reflection: A deeper look. Opt. Soc. Am. 17, 509-519 (1978)
- S. Zhu, A. W. Yu, D. Hawley, and R. Roy. Frustrated total internal reflection: A demonstration and review. Am. J. Phys. 54, 7, 601-607 (1986), http://www.physics.princeton.edu/~mcdonald/examples/optics/zhu_ajp_54_601_86.pdf
- Seigo Igaki, Shin Eguchi, Fumio Yamagishi, Hiroyuki Ikeda, and Takefumi Inagaki. Real-time fingerprint sensor using a hologram. Appl. Optics 31, 11, 1794-1802 (1992), http://www.xphotonics.com/tech/Finger%20Print/Real-time%20fingerprint%20sensor%20using%20a%20hologram.pdf

Background reading

- Jefferson Y. Han. Low-cost multi-touch sensing through frustrated total internal reflection. Proc. UIST (Seattle, Oct. 23-27, 2005), pp. 115-118
- Salvatore Esposito. Universal photonic tunneling time. Phys. Rev. E 64, 026609 (2001), arXiv:physics/0102020v2 [physics.optics]
- A. Haibel and G. Nimtz. Universal tunnelling time in photonic barriers. Ann. Phys. (Leipzig), 10, 8, 707-712 (2001), arXiv:physics/0009044v1 [physics.gen-ph]
- Yizhuang You, Xiaohan Wang, Sihui Wang,Yonghua Pan, and Jin Zhou. A new method to demonstrate frustrated total internal refection. Am. J. Phys. 76, 3, 224-228 (2008), http://physlab.lums.edu.pk/images/6/6c/Frustrated_tir2.pdf
- G. Joos, I. M. Freeman. Theoretical Physics (Dover, New York, 1950)
- Robert E. Gaensslen. Advances in fingerprint technology (CRC Press, 2001)
- Д. В. Сивухин. Курс общей физики. — М.: Наука, 1988. — т. 4, 5
- Луи де Бройль. Революция в физике. — М.: Госатомиздат, 1963
- Bruce W. Smith, Yongfa Fan, Jianming Zhou, Neal Lafferty, Andrew Estroff. Evanescent wave imaging in optical lithography. In: Optical Microlithography XIX, Proc. SPIE 6154, pp. 100-108 (2006), http://www.rit.edu/kgcoe/microsystems/lithography/research/imagetheory/SPIE_6154-10_smith-1.pdf
- Ignacy Gryczynski, Zygmunt Gryczynski, and Joseph R. Lakowicz. Two-photon excitation by the evanescent wave from total internal reflection. Anal. Biochem. 247, 69–76 (1997), http://cfs.umbi.umd.edu/cfs/reprints/Two-Photon%20Excitation%20by%20the%20Evanescent%20Wave.pdf
- A. A. Stahlhofen and G. Nimtz. Evanescent modes are virtual photons. Europhys. Lett. 76, 2, 189 (2006)

Open questions

- What is the role of liquid in the effect? How does the image depend on its refractive index?

- What happens, if there is no liquid at all in the glass? How to quantitatively characterize the dependence of visible pattern on the amount of liquid involved?

- On what does the visible light intensity ("brightness of fingerprints") depend?
    - applied force → "effective contact area"?
    - observation angle and the position of ambient light sources?
    - amount of grease/water on fingertips?
    - …?

Key questions

- In the simplest case, if there are no fingers touching the glass, why there is nothing visible through the walls?
- Above all, what is the physical reason of the fingerprint effect? Is the visible color of fingerprints determined by scattering, reflection, adsorption, or the interplay between all of them?
- What is the approximate gap between the skin and the glass for the raised epidermal ridges, and for the grooves between them? How to best approach the question, as the finger surface is fractal-like and the gap varies considerably from point to point?
- What is the approximate length scale for roughness of the glass surface and of the finger skin? Is it physically correct to speak of such length scales? What other approaches would be more useful?
- How does the effect depend on skin properties, and is the finger grease relevant?
- How does the apparent contact area depend on length scale?
- What are the dependences of the reflective indexes in the system the angle of incidence? Are the Fresnel's relations relevant?
- Does the effect depend on wavelengths of incident or scattered light, refractive indexes of media in question, surface properties?
- Is it possible to establish a model experimental system to measure the radiation density at controlled distances from the interface? What range of wavelength would be optimum for such a system?
- Many approaches and concepts may emerge at discussions (momentum of photons, Pointing vector, tunneling, evanescent wave, potential barrier, probability distribution, absorption, scattering.) Can you discuss their relevance and re-formulate your explanation with a different basic concept?
- Is there a physically relevant time lag for the wave to pass through the gap?
- How to best record the visible fingerprint image for further analysis, and what information can be retrieved from such images?

Problem No. 12 "Levitating spinner"

A toy consists of a magnetic spinning top and a plate containing magnets (e.g. "Levitron"). The top may levitate above the magnetic plate. Under what conditions can one observe the phenomenon?

LEVITRON
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Spin the top - and watch it float! The Levitron spins and surfs on magnetic waves! Pass your hand above, underneath, and around the top. It will continue to spin and float only touching air! The LEVITRON floats free in space, supported only by the repelling magnetic force produced by permanent magnets (no batteries required!). A scientific theorem, that was advanced over a century ago, states that this is impossible - yet this amazing top levitates right before your eyes! You must see it to believe it!

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What spatial arrangements of magnets in the base, and in the spinning top, are necessary? Are there limitations for minimum or maximum speed of spinning?

IYPT history

- **1.** Invent yourself (5th IYPT, 1992)
  - The design of future rapid trains includes a "magnetic suspender". Develop and construct an experimental model of such a suspender.
- **12.** Rolling magnets (19th IYPT, 2006)
  - Investigate the motion of a magnet as it rolls down an inclined plane.
- **14.** Magnetic spring (23rd IYPT, 2010)
  - Two magnets are arranged on top of each other such that one of them is fixed and the other one can move vertically. Investigate oscillations of the magnet.

Background reading

- Levitron. http://www.levitron.com/
- Wikipedia: Levitron, http://en.wikipedia.org/wiki/Levitron
- T. B. Jones, M. Washizu, and R. Gans. Simple theory for the Levitron. J. Appl. Phys., 82, 883-888 (1997), http://heligone.free.fr/levitron/Levitron_rochester.simple.pdf
- R. F. Gans, T. B. Jonesm and M. Washizu. Dynamics of the Levitron. J. Phys. D. 31, 671 (1998)
- M. D. Simon, L. O. Heflinger, and S. L. Ridgway. Spin stabilized magnetic levitation. Am. J. Phys. 65, 286-282 (1997), http://www.physics.princeton.edu/~mcdonald/examples/mechanics/simon_ajp_65_286_97.pdf
- M. V. Berry. The Levitron: an adiabatic trap for spins. Proc. Roy. Soc. London, 452 1207-1220 (1996)
- H. R. Dullin, R. W. Easton. Stability of the Levitron™. Physica D 126, 1-17 (1999)
- Holger R. Dullin and Robert W. Easton. Stability of Levitrons. ZAMM 79, S167-S170 (1999), http://chiusir.net/student/2006-6b/A_MECHANICS/levitron_Chiusir/LeviGAMM.pdf
- J. M. McBride. A Toy Story: The chemical relevance of Earnshaw's theorem, and How the Levitron® circumvents it (Gordon Research Conference on Physical-Organic Chemistry June 29-July 4, 1997), http://www.chem.yale.edu/~chem125/levitron/levitron.html
- Michael V. Berry. Frequently Asked Questions About the Levitron. http://www.lauralee.com/physics.htm
- Mike and Karen Sherlock. The hidden history of the Levitron. http://www.amasci.com/maglev/lev/expose1.html
- P. Flanders, S. Gov, S. Shtrikman, and H. Thomas. On the spinning motion of hovering magnetic top. Physica D, 126, 225-235 (1999)
- S. Djaković, S. Simić. A note on stability of hovering magnetic top. Proc. 2nd IConSSM 2009, http://mechanics.ftn.uns.ac.rs/zaposleni/srboljub.simic/publications/2009_Hovering_Top.pdf
- Wikipedia: Magnetic levitation, http://en.wikipedia.org/wiki/Magnetic_levitation

Background reading

- S. Earnshaw. On the nature of the molecular forces which regulate the constitution of the luminiferous ether. Trans. Cambridge Philos. Soc., 7, 97-112 (1842)
- R. Edge. Levitation using only permanent magnets. Phys. Teach. 33, 252-253 (1995)
- E. H. Brandt. Levitation in physics. Science 243, 349-355 (1989)
- C. Elbuken, M. B. Khamesee, and M. Yavuz. Eddy current damping for magnetic levitation: downscaling from macro- to micro-levitation. J. Phys. D: Appl. Phys. 39, 3932-3938 (2006)
- G. Genta, C. Delprete, and D. Rondano. Gyroscopic stabilization of passive magnetic levitation. Meccanica 34, 6, 411-424 (Dec. 1999)
- Magnetic Levitation (Georgia State University), http://hyperphysics.phy-astr.gsu.edu/Hbase/solids/maglev.html
- O. I. Gorskii and E. A. Zel'dina. The stability of the vertical oscillations of a body in a dynamic potential well. Int. App. Mech. 36, 10, 1393-1397 (Oct. 2000)
- B. P. Mann and N. D. Sims. Energy harvesting from the nonlinear oscillations of magnetic levitation. J. Sound Vibr. 319, 1-2, 515-530 (Jan. 2009)
- P. Doherty. Magnetic Oscillators. http://www.exo.net/~pauld/summer_institute/summer_day16magnetism/MagneticOscillators/MagneticOscillators.html
- How can you magnetically levitate objects? http://my.execpc.com/~rhoadley/maglev.htm
- A. K. Geim, M. D. Simon, M. I. Boamfa, and L. O. Heflinger. Magnet levitation at your fingertips. Nature 400, 323-324 (1999)
- Calibrating an oscillating magnet in the field of a current carrying coil (Bowling Green State University), http://feynman.bgsu.edu/physics/rm137/expt.2.10-mag.fld/Expt.2.10-intro.html

Background reading

- M. J. Moloney. Coupled oscillations in suspended magnets. Am. J. Phys., 76, No. 2, 125-128 (February 2008), http://newton.phys.uaic.ro/data/pdf/Oscilatii_cuplate.pdf
- Y. Kraftmakher. Pendulums are magnetically coupled. Phys. Educ., 43, 248-251 (2008)
- Damping of Levitated Magnet Motion (Georgia State University), http://hyperphysics.phy-astr.gsu.edu/hbase/Solids/maglev5.html
- R. F. Post and D. D. Ryutov. The Inductrack: A Simpler Approach to Magnetic Levitation, http://www.askmar.com/Inductrack/1999-9%20Simpler%20Approach.pdf
- M. D. Simon, L. O. Heflinger, and A. K. Geim. Diamagnetically stabilized magnetic levitation. Am. J. Phys. 69, 6, 702-713 (2001), http://www.physics.ucla.edu/marty/diamag/ajp601.pdf
- M. D. Simon and A. K. Geim. Diamagnetic levitation: Flying frogs and floating magnets (invited). J. App. Phys. 87, 9, 6200-6204 (2000), http://www.physics.ucla.edu/marty/diamag/diajap00.pdf
- Magnetic Levitation - Science is Fun. http://www.levitationfun.com
- Magnetic Toys. The physics display case in the East Bridge hallway at Caltech, http://www.its.caltech.edu/~atomic/display/displaycase.htm
- B. P. Mann and N. D. Sims. Energy harvesting from the nonlinear oscillations of magnetic levitation. J. Sound Vibr. 319, 1-2, 515-530 (Jan. 2009)
- Magnetic levitation (from Eltimple, April 30, 2007, youtube), http://www.youtube.com/watch?v=icpGonZljvA
- Magnetic levitation (from Wushu17, July 02, 2006, youtube), http://www.youtube.com/watch?v=nWTSzBWEsms
- Magnetic levitation Ferromagnetic diamagnatism (from Eltimple, March 09, 2007, youtube), http://www.youtube.com/watch?v=lsDTSUfH6UI

Background reading

- Levitation: Glass of Wine (from simerlab, Dec. 23, 2006, youtube), http://www.youtube.com/watch?v=tEu5Qkqw7Tg
- Tori Johnson and Jenna Wilson. Magnetic Levitation (2007), http://www.chem.orst.edu/courses/ch224-6/ch226/2007/Magnetic%20Levitation%20PowerPoint.ppt
- T. Ohji, S. Ichiyama, K. Amei, M. Sakui, and S. Yamada. A new conveyor system based on a passive magnetic levitation unit having repulsive-type magnetic bearings. J. Mag. Magnetic Mat. 272-276, 1, E1731-E1733 (May 2004)
- Oscillation period of a bar magnet suspended? Yahoo answers (2009), http://answers.yahoo.com/question/index?qid=20091026084159AAhOVYC
- J. Bransky. Superconductivity - A New Demonstration. Phys. Teach. 28, 392 (1990)
- A. M. Wolsky, R. F. Giese and E. J. Daniels. The new superconductors: prospects for applications. Sci. Am. 260, 60 (Feb 1989)
- Mark T. Thompson. Eddy current magnetic levitation: models and experiment. IEEE Potentails 40-46 (2000), http://www.classictesla.com/download/ieee_potentials_2000.pdf
- Donald W. Kerst . Levitated ball. In: Magnetism, Physics Demonstrations (University of Wisconsin-Madison), http://sprott.physics.wisc.edu/demobook/chapter5.htm
- T. Hikihara, F. C. Moon. Chaotic levitated motion of a magnet supported by semiconductor. Phys. Lett. A 191, 3-4, 279-284 (Aug. 1994)
- K. Halbach. Application of permanent magnets in accelerators and electron storage rings. J. App. Phys. 57, 3605 (1985)

Key questions

- The problem has been extensively investigated before. How should we approach the task and what aspects to investigate, in order not to repeat earlier work and seriously contribute to the understanding of the tricky problem?

- What is your conclusion on the translational and rotational stability of the spinner? What interactions maintain the spinner levitated? How to describe these interactions quantitatively? What are the opportunities in analyzing the physics of different magnetic levitation toys, not only Levitron as such? Is a potential well a must for any magnetic levitator?

- What are the critical conditions for rotational instability and further re-orientation of poles?

- What are the roles for the air resistance, or induction heating? What is the expected and actual lifetime for levitation?

- How to measure the magnetic field in the vicinity of the spinner without influencing the system as such?

- What parameters of the magnetic spinner are relevant? (magnetic moment? mass? moment of inertia?) What other interactions, besides magnetic and gravitational, are relevant?

- What possible oscillatory modes may be observed? How to classify them? What is the total energy of the system, and what are the contributions of potential energies and kinetic energy of the spin?

- How to best record and analyze the rotation, oscillations, or stability of the spinner? (stroboscopic, time lapse video?)

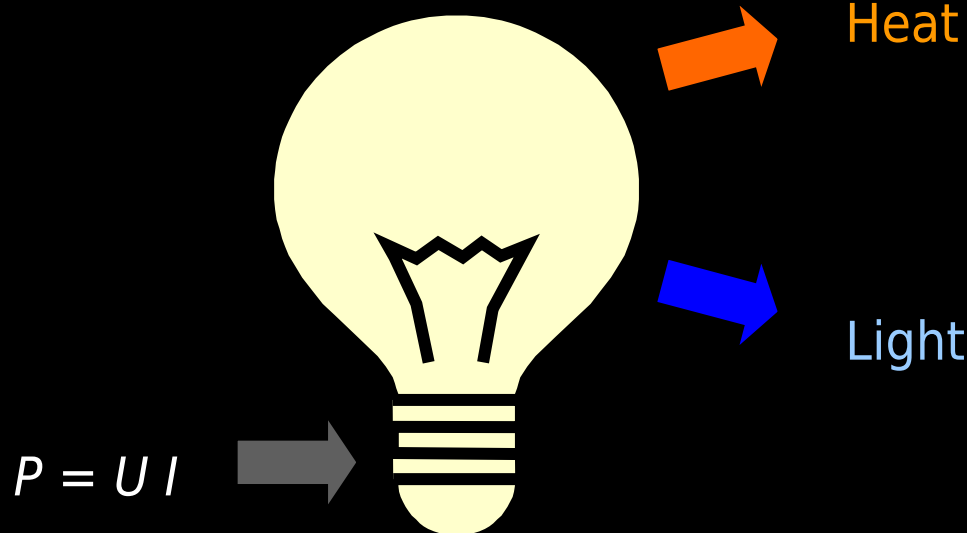- Above all, what is your conclusion on the problem?

Problem No. 13 "Light bulb"

What is the ratio between the thermal energy and light energy emitted from a small electric bulb depending on the voltage applied to a bulb?

(Very) basic ideas

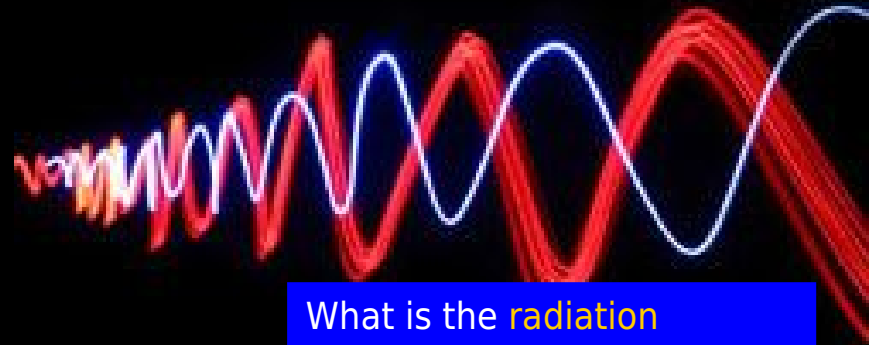Metal wires are heated by filament → quick heat transfer by metal?

Air is heated at interface with glass bulb (via inert gas) → convection?

Heat

Light

$P = U I$

What is the radiation spectrum for a light bulb? Does it only produce optical radiation?

It is actually our task to investigate those, and other, paths for energy transfer :-)

What is the difference between "small" and "large" bulbs?

IYPT history

- **7.** Incandescent lamp (9th YPT, Correspondence Competition, 1987)
  - An incandescent lamp is connected to a power circuit of
    - a) direct current
    - b) alternate current with a frequency of *50 Hz*
  - Study the current in the circuit as a function of voltage on the lamp. Estimate the amplitude of temperature oscillations of the filament in a lamp connected to AC circuit of *50 Hz*.
- **11.** Incandescent lamp (1st IYPT, 1988)
  - It is said that two *60 W* light bulbs shine brighter than three *40 W* bulbs. Is it true? Investigate the change of light emission and the change of light bulb's lifetime at a small change of supplied voltage.
- **15.** Incandescent lamp (5th IYPT, 1992)
  - Determine the amplitude of temperature oscillations of the coil of an incandescent lamp connected to AC circuit.
- **6.** Transmission of signals (13th IYPT, 2000)
  - Using a bulb, construct the optimum transmitter of signals without any modulation of the light beam between transmitter and receiver. Investigate the parameters of your device. The quality of the device is defined by the product of the information rate (bits/sec) and the distance between transmitter and receiver.
- **14.** Illumination (13th IYPT, 2000)
  - Two bulbs, *100* and *40 watts*, respectively, illuminate a table tennis ball placed between them. Find the position of the ball, when both sides of the ball appear to be equally lit. Explain the result.
- **10.** Tungsten lamp (16th IYPT, 2003)
  - The resistance of the tungsten filament in a light bulb shows a strong temperature dependence. Build and demonstrate a device based on this characteristic.
- **1.** Filament (20th IYPT, 2007)
  - There is a significant current surge when a filament lamp is first switched on. Propose a theoretical model and investigate it experimentally.

Background reading

- John W. Dewdney. Energy loss from the filament of an incandescent lamp. Am. J. Phys. 28, 2, 89-91 (1960)
- D. MacIsaac, G. Kanner, and G. Anderson. Basic physics of the incandescent lamp (lightbulb.) Phys. Teach. 37, 9, 520-525 (1999), http://www.cce.ufes.br/jair/web/TPTDec99Filament.pdf
- Harvey S. Leff. Illuminating physics with light bulbs. Phys. Teach. 28, 30–35 (1990)
- D. C. Agrawal, H. S. Leff, and V. J. Menon. Efficiency and efficacy of incandescent lamps. Am. J. Phys. 64, 649-654 (1966)
- John M. Anderson and John S. Saby. The electric lamp: 100 years of applied physics. Phys. Today, 32-40 (Oct. 1979)
- H. Hewitt and A. S. Vause (eds). Lamps and Lighting (American Elsevier Publishing Co., New York 1966)
- B. Denardo. Temperature of a lightbulb filament. Phys. Teach. 40, 101–105 (2002)
- V. J. Menon and D. C. Agrawal. Lifetimes of Incandescent Bulbs. Phys. Teach. 41, 100 (2003)
- D. C. Agrawal and V. J. Menon. Lightbulb exponent-rules for the classroom. IEEE Trans. Educ. 43, 262–265 (2000)
- D. C. Agrawal and V. J. Menon. Life-time and temperature of incandescent lamps. Phys. Educ. 33, 55–58 (1998)
- D. C. Agrawal and V. J. Menon. Incandescent bulbs: Illuminating thermal expansion. Quantum 8, 35–36 (1998)
- W. S. Wagner. Temperature and color of incandescent lamps. Phys. Teach. 29, 176–177 (1991)
- Paul Gluck and John King. Physics of incandescent lamp burnout. Phys. Teach. 46, 29 (2008)

Background reading

- D. A. Clauss, R. M. Ralich, and R. D. Ramsier. Hysteresis in a light bulb: Connecting electricity and thermodynamics with simple experiments and simulations. Euro. J. Phys 22, 385 (2001)
- H. Richard Crane. Making light bulbs last forever. Phys. Teach. 21, 606–607 (1983)
- E. J. Covington. Hot-spot burnout of tungsten filaments. J. Illum. Eng. Soc. 2(4), 372 (1973)
- H. Jones and I. Langmuir. The characteristics of tungsten as functions of temperature. Gen. Elec. Rev. 30, 310, 354, 408(1927)
- I. R. Edmonds. Stefan-Boltzmann law in the laboratory. Am. J. Phys. 36, 845 (1968)
- B. S. N. Prasad and R. Mascarenhas. A laboratory experiment on the application of Stefan's law to tungsten filament electric lamps. Am. J. Phys. 46, 420 (April 1978)
- I. Cooper. Physics with a car headlamp and a computer. Phys. Educ. 32, 197 (May 1997)
- A. James Mallmann. Lamp lifetimes. Phys. Teach. 46, 196 (2008)
- V.J. Menon and D.C. Agrawal. A theory for the mortality curve of filament lamps. J. Mater. Eng. Performance 16, 1-6 (2007)
- W. E. Forsythe and A. G. Worthing. The properties of tungsten and characteristics of tungsten lamps. Astrophys. J. 61, 146-157 (1925)
- Z. S. Voznesenskaya and V. F. Soustin. Incandescent tungsten filament burnouts in vacuum and in inert gas atmospheres. J. Techn. Phys. (USSR) 9, 399-405 (1939)
- W. A. Anderson, E. M. Passmore. Incandescent lamp failure mechanisms. J. Illum. Engg. Soc. 5, 31-37 (1975)
- R. Raj and G. W. King. Life prediction of tungsten filaments in incandescent lamps. Metallurg. Trans A. 9A, 941-946 (1978)

Background reading

- O. Horacsek. Properties and failure modes of incandescent tungsten filaments. IEE Proc. 127A, 134-141 (1980)
- V. J. Menon, D. C. Agrawal. A model for mass loss in burned-out filaments of incandescent lamps. Leukos: J. Illum. Eng. Soc. 1, 93-100 (2004)
- E. J. Covington. The life-voltage exponent for tungsten lamps. J. Illum. Eng. Soc. 2, 83-91 (1973)
- V.J. Menon and D.C. Agrawal. A theory of filament lamp's failure statistics. Eur. Phys. J. Appl. Phys. 34, 2, 117-121 (2006)
- Bruce Denardo. Temperature of a lightbulb filament. Phys. Teach. 40, 2, 101-105 (2002)
- Biswajit Ray. Don't zap that light bulb! Phys. Teach. 44, 374 (2006)
- Lawrence D. Woolf. Seeing the light: The physics and materials science of the incandescent light bulb (GA Sciences Education Foundation, Feb. 20, 2002), http://www.sci-ed-ga.org/modules/materialscience/light/Light_bulb.pdf
- А. Иванов. Электрические лампы // Техническая энциклопедия, т. 11. — М.: АО «Советская энциклопедия», 1930, стр. 831—864
- Wikipedia: Light bulb, http://en.wikipedia.org/wiki/Light_bulb
- Wikipedia: Black body, http://en.wikipedia.org/wiki/Black_body
- Wikipedia: Color temperature, http://en.wikipedia.org/wiki/Color_temperature
- Kevin Cunningham. Light sources, http://www.mindspring.com/~smskjc/lightk.htm
- Resistance and temperature, http://www.iop.org/Our_Activities/Schools_and_Colleges/Teaching_Resources/Teaching%20Advanced%20Physics/Electricity/Electrical%20Resistance/file_3133.doc

Background reading

- К. Д. Краевичъ. Учебникъ физики, XXIV изд. — С.-Пб., 1912, стр. 342—347
- How light bulbs work (howstuffworks.com), http://science.howstuffworks.com/light-bulb2.htm, http://home.howstuffworks.com/light-bulb1.htm
- Edward J. Covington's Early Incandescent Lamps. http://home.frognet.net/~ejcov/
- Robert Friedel and Paul Israel. Edison's electric light: biography of an invention (Rutgers University Press, New Brunswick, 1987)
- Light source spectra (Cornell University, 2001), http://www.graphics.cornell.edu/online/measurements/source-spectra/index.html
- И. Алексеев, Д. Свирида. И светит и греет // Квант, №3, 1982, стр. 17—19, http://ilyam.org/Alexeev_Svirida_III_TUF_I_svetit_i_greet_Kvant_3_1982_17-19.pdf
- Problems at Aalborg Universitet, http://www.face.auc.dk/courses/3sem/Varmeledning/Solution1.doc
- Wikipedia: Stefan-Boltzmann law, http://en.wikipedia.org/wiki/Stefan%E2%80%93Boltzmann_law
- Wikipedia: Wien's displacement law, http://en.wikipedia.org/wiki/Wien's_displacement_law
- И. Соколов. Вечная электрическая лампочка? // Квант, №8, 1989, стр. 2—7, 16, http://kvant.mirror1.mccme.ru/1989/08/vechnaya_elektricheskaya_lampo.htm

Key questions

- How does the ratio between thermal and light energies evolve over time, when the lamp is switched on?

- Is there a way to directly measure the temperature of the filament and other elements of the lamp? Is it possible to measure or calculate the radiation intensity?

- What physical parameters of the system may be relevant? (voltage provided by the power supply? resistance of the filament as a function of temperature? inductance of the filament? heat conductivity of contact wires and the gas? surface properties of the filament?)

- What is the radiation spectrum of the lamp and does it evolve over time? Are the Planck's law and the black body approximation relevant?

- The filament in a "used" lamp is possibly thinner and more likely to burn out. How does it influence on ratio between energies in question?

- In the end, what are the overall energy losses via radiation and via heat transfer? What amount of heat is leaving through contact wires and through gas and glass? What are the time scales for these energy losses?

Problem No. 14 "Moving cylinder"

Place a sheet of paper on a horizontal table and put a cylindrical object (e.g. a pencil) on the paper. Pull the paper out. Observe and investigate the motion of the cylinder until it comes to rest.

IYPT history

- **4.** Rolling friction (2nd IYPT, 1989)
  - Investigate how does the friction force depend on speed. For example, study the rolling of a wooden disk on the wooden surface of a table.

Background reading

- D. E. Shaw. Frictional force on rolling objects. Am. J. Phys. 47, 887–888 (1979), http://www.physics.princeton.edu/~mcdonald/examples/mechanics/shaw_ajp_47_887_79.pdf
- A. Pinto and M. Fiolhais. Rolling cylinder on a horizontal plane. Phys. Educ. 36, 250-254 (2001), http://nautilus.fis.uc.pt/personal/mfiolhais/artigosdid/did4.pdf
- T. Pöschel, T. Schwager, and N. V. Brilliantov. Rolling friction of a hard cylinder on a viscous plane. Eur. Phys. J. B 10, 1, 169-174 (1999), arXiv:cond-mat/9809053v1 [cond-mat.mtrl-sci]
- C. Carnero, J. Aguiar, and J. Hierrezuelo. The work of the frictional force in rolling motion. Phys.
- Educ. 28, 225–227 (1993)
- J. A. G. McClelland. Friction and related phenomena. Phys. Educ. 26, 234–237 (1991)
- A. Salazar, A. Sánchez-Lavega, and M. A. Arriandiaga. Is the frictional force always opposed to the motion? Phys. Educ. 25, 82–85 (1990)
- C. A. Sousa and E. P. Pina. Aspects of mechanics and thermodynamics in introductory physics: an illustration in the context of friction and rolling. Eur. J. Phys. 18, 334–337 (1997)
- Rotational Dynamics: Rolling Spheres/Cylinders (physicslab.org), http://dev.physicslab.org/Document.aspx?doctype=3&filename=RotaryMotion_RotationalDynamicsRollingSpheres.xml
- Eugene Butikov. Inertial rotation of a rigid body. Eur. J. Phys. 27, 913–922 (2006)
- Combined translational and rotational motion. In: Richard Fitzpatrick. Classical Mechanics, an introductory course (University of Texas at Austin, 2006), http://farside.ph.utexas.edu/teaching/301/lectures/node108.html
- J. L. Stanbrough. Falling, Sliding and Rolling (2008), http://www.batesville.k12.in.us/physics/phynet/mechanics/RotMechanics/fall_slide_roll.htm
- A. O. Belyakov, A. P. Seyranian. The hula-hoop problem. Doklady Physics 55, 2, 99-104 (2010)
- T. Cluff, D. G. E. Robertson, and R. Balasubramaniam. Kinetics of hula hooping: An inverse dynamics analysis. Human Movement Sci. 27, 4, 622-635 (2008)
- Richard Fitzpatric. Worked example 8.7: Rotating cylinder (University of Texas at Austin, 2006), http://farside.ph.utexas.edu/teaching/301/lectures/node115.html

Key questions

- Is the problem all about the steady rolling? Should we also investigate other rotational modes, such as the revolution around an axis normal to the principal axis of the cylinder? (e.g. passing through the center-of-the-masses, or not?)
- How does the initial motion of the sheet determine further dynamics of the cylinder? What is the role of the speed or acceleration of the sheet, and its exact 3D trajectory?
- How does the co-ordinate, as well as translational and angular speeds and accelerations depend on time?
- To what degree the motion is reproducible, if the experiment is repeated?
- What is the direction of rolling in dependence of initial parameters? Can the pencil show the hula hooping effect? Is there a possibility of slipping?
- How does evolve over time the ratio between the kinetic energy of rotation and the kinetic energy of translational motion?
- An exponential or likewise decceleration means very slow motion at certain time scales. What is the kinetics of the cylinder before the final rest, and what additional forces or interactions may influence on it?
- What physical parameters of the cylinder may determine the quantitative or qualitative (e.g. rotational modes) features of the dynamics? (length? density? shape? surface friction coefficients?)
- Are any aerodynamic forces relevant to the problem? How significant is air resistance?
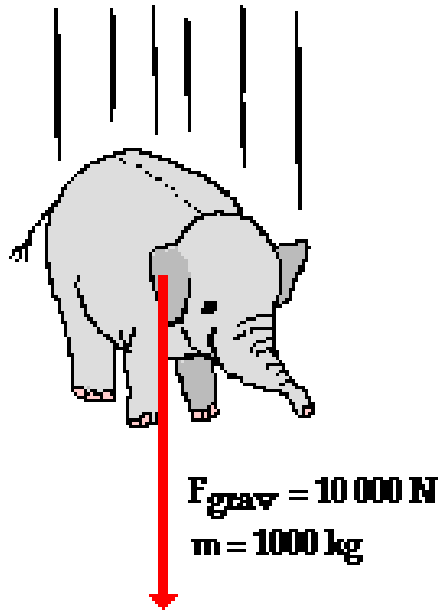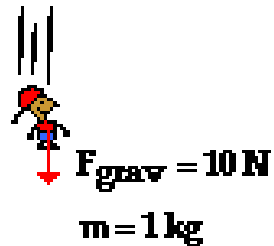- Is it worth modeling the system numerically?

Problem No. 15 "Slow descent"

Design and make a device, using one sheet of A4 80 g/m² paper that will take the longest possible time to fall to the ground through a vertical distance of 2.5 m. A small amount of glue may be used. Investigate the influence of the relevant parameters.

(Very) basic ideas

$F_{grav} = 10\,000\,N$
$m = 1000\,kg$

$F_{grav} = 10\,N$
$m = 1\,kg$

$a = \dfrac{F_{net}}{m} = \dfrac{10\,000\,N}{1000\,kg}$

$a = \dfrac{F_{net}}{m} = \dfrac{10\,N}{1\,kg}$

$a = 10\,m/s/s$

$a = 10\,m/s/s$

F_{air}

F_{grav}

F_{air}

F_{grav}
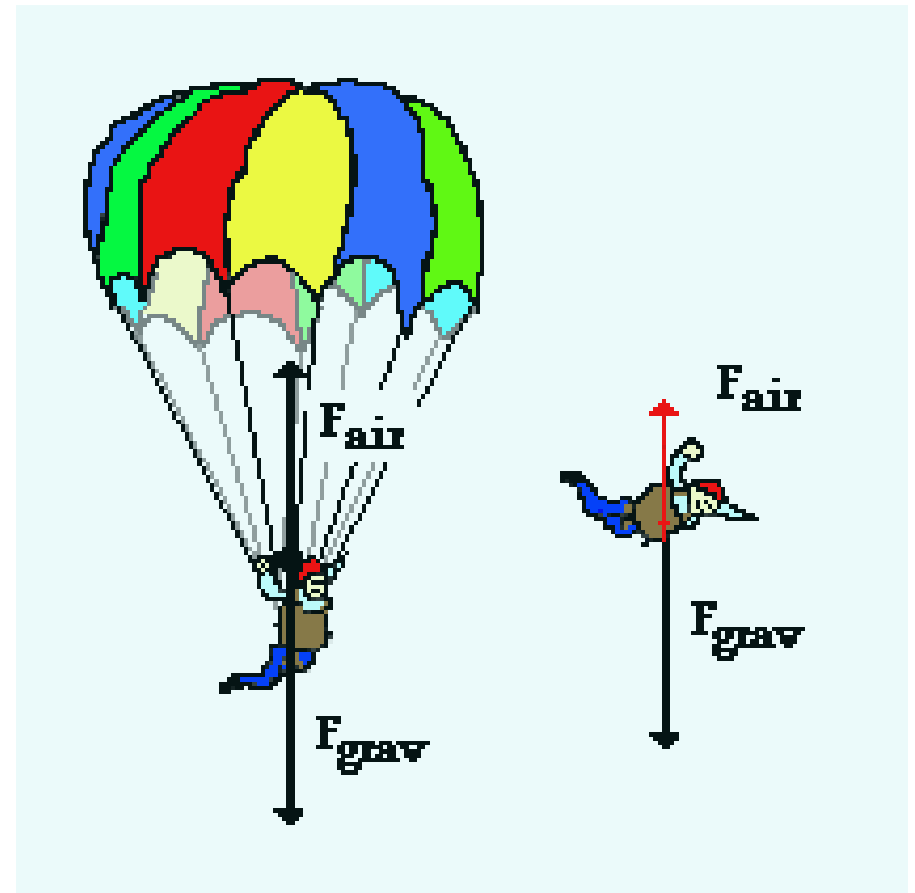
Vacuum, no air drag → *a≠f(mass, shape)*

Air drag → *a≠f(mass)*, *a=f(shape)*

http://www.physicsclassroom.com/class/newtlaws/u2l3e.cfm

Brainstorming what model to choose?

Unmodified paper sheet

Paper airglider
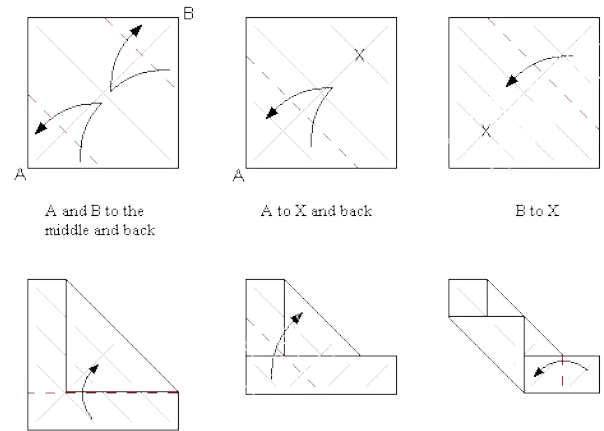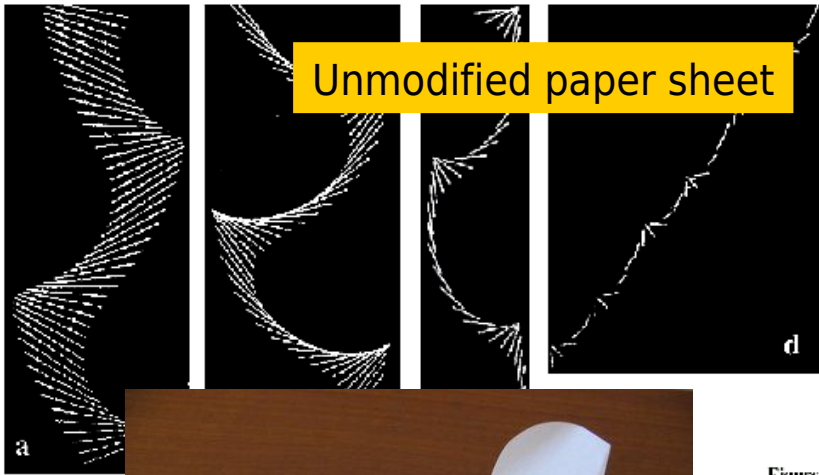
Paper maple seed
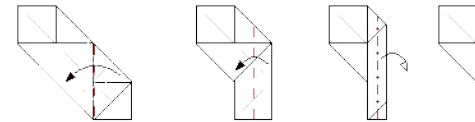
Paper propeller

Paper parachute

Hey, the problem is in physics and not in checking all possible engineering concepts!

Maximizing the descent time?
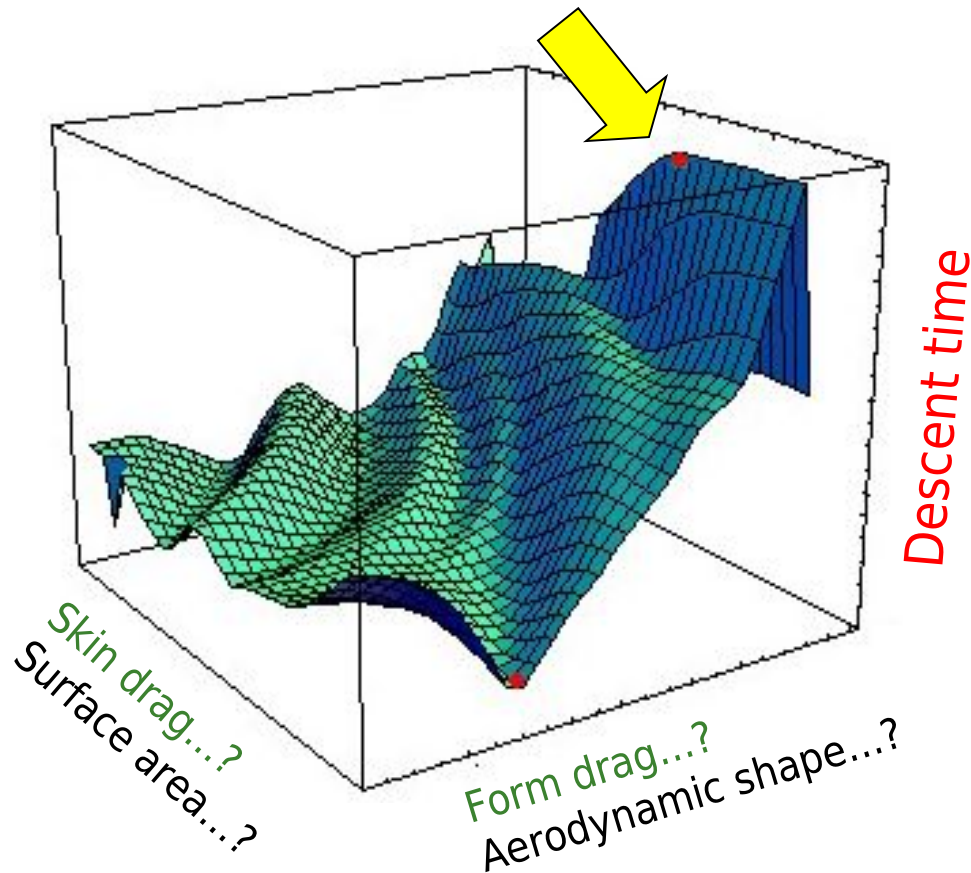
- We are looking for a global extremum of a function with multiple variables
- Some are rather fixed, some are not

- Amount of material? (fixed?)
- Initial height? (fixed?)
- Air density and viscosity? (fixed?)
- Ambient airflows (wind), not induced by the devise itself? (fixed as zero?)
- Surface properties? (fixed or not?)
- Aerodynamic shape (not fixed?)
- Surface area (not fixed?)
- Linear dimensions, e.g. cross-section (not fixed?)

Energy conservation approach…?
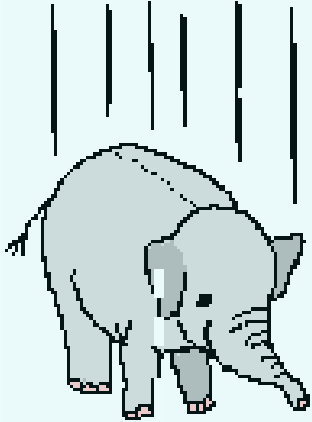
$U = mgh$
$mv^2/2 = 0$
$I\omega^2/2 = 0$
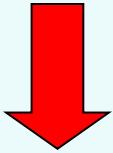
That means the minimum descent time!

$U = 0$
$mv^2/2 = mgh$
$I\omega^2/2 = 0$

$U = 0$
$mv^2/2 \to 0$:-)
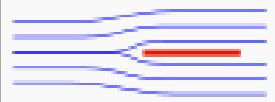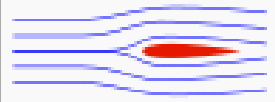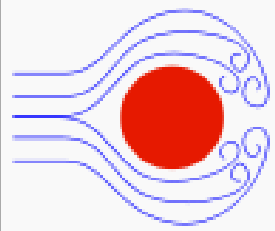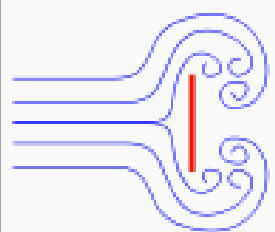
How to achieve it?

How to maximize the descent time…?

- Make the device transferring its initial potential energy into anything but kinetic energy of vertical descent?
  - into kinetic energy of rotational motion? (rotating propeller?)
  - into kinetic energy of horizontal motion? (glider?)
  - into kinetic energy of airflow or into fluid friction? (specific shape to induce turbulence, higher air drag?)
  - into vibrations, or elsewhere? (any ideas how?)

- Make the device experiencing higher air resistance?
  - form drag → adjusting shape and size
  - skin drag → adjusting surface area

- What about the stiffness of the entire construction?
  - can internal motion and friction in a non-rigid body be helpful?

Shape and flow	Form drag	Skin friction
	0%	100%
	~10%	~90%
	~90%	~10%
	100%	0%

To keep in mind…

- Is the drag always proportional to translational speed? What about rotational speed, if the device rotates?
- Is the air density constant in all points around the falling body?
- How does the aerodynamic behavior depends on Reynolds' number? Is the Reynolds number constant over time of flight?
- Is the air viscosity not at all relevant?

- How do the translational and angular speeds and accelerations for your device depend on time?
- Is there any regularity in the spatial orientation of the device during falling?
- What features of the device's geometry make it fall as it falls?
- From the energy point of view, what is the initial potential energy (*mgh*) in comparison to translational or rotational kinetic energies during different stages of the flight?

Tricky points: interpretation of the task

- Can we use only a fraction of the A4 sheet?
  - A tiny paper particle will descend for the longest time, and a nanoscale paper particle will never descend due to Brownian motion. But are we violating the task?
- If no, can we make a highly porous device by grinding the entire A4 sheet into dry fibers and stabilizing it with an aerosole of "a small amount of glue" ("dandelion")
  - Larger surface area means higher air drag. But are we violating the task?
- Can we focus efforts on a glider or a paper plane?
  - The vertical speed (descent rate) will be quite small, but can we say this motion is "falling"?
- Certain devices may require a particular "lauch procedure" (to establish a good angle of attack, to gain an initial torque, or a spatial orientation)
  - Do we violate the task by imposing any of such conditions?
- Finally, what about making a hot-air paper balloon with "a small amount of glue" as fuel?
  - It may look like an unethical, forbidden trick, but is such a solution consistent with the task?
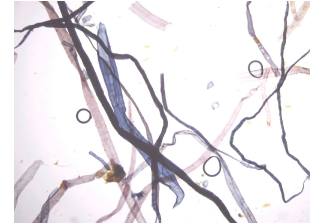
IYPT history

- **9.** Passive motor (4th IYPT, 1991)
  - An apple dropped from a balcony of a multi-storey building will slowly descend into the hands of your friend if a propeller cut out of rigid paper is attached to this apple with a match. Explain the principle of work for such a parachute and study the dependence of the drag force on the speed of falling and on the sizes of the propeller's blades.
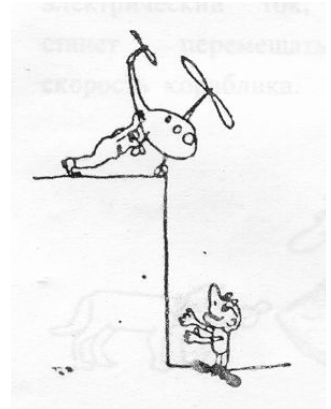
- **1.** Invent yourself (11th IYPT, 1998)
  - Construct an aeroplane from a sheet of paper (A4, 80 g/m^2). Make it fly as far and/or as long as possible. Explain why it was impossible to reach a greater distance or a longer time.
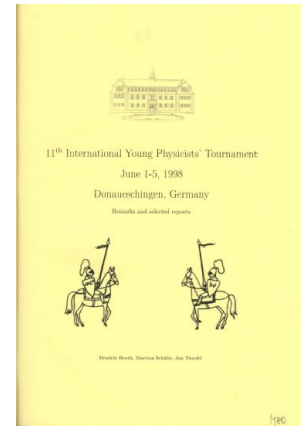
- **5.** Dropped paper (12th IYPT, 1999)
  - If a rectangular piece of paper is dropped from a height of a couple of meters, it will rotate around its long axis whilst sliding down at a certain angle. How does this angle depend on various parameters?

- **2.** Winged seeds (21st IYPT, 2008)
  - Investigate the motion of falling winged seeds such as those of the maple tree.

11th International Young Physicists' Tournament
June 1-5, 1998
Donaueschingen, Germany
Remarks and selected reports

Problem No. 2 "Winged seed"
Investigate the motion of falling winged seeds such as those of the maple tree.

Background reading

- Л. Прандтль — О. Титьенс. Гидро- и аэромеханика. — М., Л.: ГТТИ, 1933
- Г. Кирхгоф. Механика. Лекции по математической физике. — М.: Изд. АН СССР, 1962
- Л. Г. Лойцянский. Механика жидкости и газа. — М., Л.: ГИТТЛ, 1950
- Дж. Бэтчелор. Введение в динамику жидкости. — М.: Мир, 1973
- Chapter 3: Principles of flight (seacadets.org), http://compass.seacadets.org/pdf/nrtc/an/14014_ch3.pdf
- Paper maple seed on Earth and in space (Toys in space II. NASA), http://www.nasa.gov/pdf/151731main_Toys.In.Space.II.pdf
- Л. Прандтль — О. Титьенс. Гидро- и аэромеханика. — М., Л.: ГТТИ, 1933
- Г. Кирхгоф. Механика. Лекции по математической физике. — М.: Изд. АН СССР, 1962
- Л. Г. Лойцянский. Механика жидкости и газа. — М., Л.: ГИТТЛ, 1950
- Дж. Бэтчелор. Введение в динамику жидкости. — М.: Мир, 1973
- R. A. Norberg. Autorotation, self-stability, and structure of single-winged fruits and seeds (samaras) with comparative remarks on animal flight. Biol. Rev. 48, 561-596 (1973)
- A. Rosen and D. Seter. Vertical autorotation of a single-winged samara. J. Appl. Mech. 58, 4, 1064-1071 (1991)
- J. Walker. The aerodynamics of the samara: winged seed of the maple, the ash and other trees: The Amateur Scientist. Sci. Am. 245, 4, 226-236 (1981)
- H. J. Lugt. Autorotation. Ann. Rev. Fluid Mech. 15, 123-147 (1983)
- D. Seter and A. Rosen. Study of the vertical autorotation of a single-winged samara. Biol. Rev. Cambridge Phil. Soc. 67, 2, 175-197 (1992)

Background reading

- L. Mahadevan. Tumbling of a falling card. Comptes rendus de l'Academie des Sciences. Series II. Mécanique, Physique, Chimie, Astronomie, 323, 11, 729-736 (1996)
- A. Belmonte, H. Eisenberg, and E. Moses. From flutter to tumble: inertial drag and Froude similarity in falling paper. Phys. Rev. Lett. 81, 2, 345-348 (1998)
- L. Mahadevan, W. S. Ryu, and A. D. T. Samuel. Tumbling cards. Phys. Fluids 11, 1, 1-3 (1999)
- D. Seter and A. Rosen. Dynamics of systems that include wings in autorotation. J. Dyn. Systems Meas. Control – Trans. ASME, 121, 2, 248-254 (1999)
- R. Mittal, V. Seshadri, and H. S. Udaykumar. Flutter, tumble and vortex induced autorotation. Theor. Comput. Fluid Dyn. 17, 165-170 (2004)
- D. Kolomenskiy and K. Schneider. Numerical simulations of falling leaves using a pseudo-spectral method with volume penalization. Theor. Comput. Fluid Dyn., 24, 1-4, 169-173 (2010)
- D. Tam, J. W. M. Bush, M. Robitaille, and A. Kudrolli. Tumbling dynamics of passive flexible wings. Phys. Rev. Lett. 104, 184504 (2010)
- David L. Finn. Falling paper and flying business cards. SIAM News 40, 4 (May 2007), http://www.siam.org/pdf/news/1123.pdf
- Terry Flower, Randi Quanbeck. A Celebration of Flight (College of St. Catherine), http://www.stkate.edu/physics/Flight/
- Slater Harrison. Build and surf an origami hang glider on a wave of air (Sciencetoymaker.org, August 22, 2010), http://www.sciencetoymaker.org/hangGlider/index.htm
- Slater Harrison. Surf an origami tumblewing on a wave of air (Sciencetoymaker.org), http://www.sciencetoymaker.org/tumblewing/index.htm

Background reading

- Wikipedia: Terminal velocity, http://en.wikipedia.org/wiki/Terminal_velocity
- Wikipedia: Free fall, http://en.wikipedia.org/wiki/Free_fall
- Wikipedia: Drag, http://en.wikipedia.org/wiki/Drag_(physics)
- Wikipedia: Parasitic drag, http://en.wikipedia.org/wiki/Parasitic_drag
- J.C. Maxwell, On a particular case of the descent of a heavy body in a resisting medium, Camb. and Dubl. Math. J., IX, 145–148 (1854)
- Yoshihiro Tanabe and Kunihiko Kaneko. Behavior of a falling paper. Phys. Rev. Lett. 73, 10, 1372-1375 (1994), http://chaos.c.u-tokyo.ac.jp/papers/pr/tanabe94.pdf
- L. Mahadevan, H. Aref, and S. W. Jones. Comment on "Behavior of a Falling Paper". Phys. Rev. Lett. 75, 7, 1420–1420 (1995)
- Umberto Pesavento, Z. Jane Wang. Falling paper: Navier-Stokes solutions, model of fluid forces, and center of mass elevation. Phys. Rev. Lett. 93, 14 (2004), http://dragonfly.tam.cornell.edu/publications/2004_PRL_Pesavento_Wang.pdf
- A. Andersen, U. Pesavento, and Z. Jane Wang. Analysis of transitions between fluttering, tumbling and steady descent of falling cards, J. Fluid Mech. 541, 91–104 (2005), http://dragonfly.tam.cornell.edu/publications/S0022112005005847a.pdf
- Falling Paper (Cornell University), http://dragonfly.tam.cornell.edu/fallingpaper.html
- Ф.В. Шмитц. Аэродинамика малых скоростей. — М.: ДОСААФ, 1963
- Principles of flight. National museum of the USAF, www.nationalmuseum.af.mil/shared/media/document/AFD-060512-004.pdf
- Paper maple seed on Earth and in space (Toys in space II. NASA), http://www.nasa.gov/pdf/151731main_Toys.In.Space.II.pdf

Key questions

- What physical parameters determine the angle of attack and the spatial orientation of the falling paper device?

- What kind of motion is preferential for the device to maximize the descent time? (stable rotational motion? gliding? translational motion?)

- What are the magnitudes of the Reynolds number for the flow around the device? Is the flow laminar or turbulent? Does the Reynolds number change with time?

- How to visualize the flow around the falling device?

- What is the actual descent rate, in comparison to the speed of horizontal displacement, for your device?

- If your device shows a maximum descent time from the height of 2.5 m, would it be still showing a best result for smaller or larger heights?

- What is the dependence of descent rate on time for your device?

Problem No. 16 "Smoke stream"

A glass jar is covered with cellophane. A tightly folded paper tube of length 4–5 cm is inserted hermetically into the jar through the cellophane cover. The tube is oriented horizontally. If one burns the outside end of the tube the dense smoke flows into the jar. Explore this phenomenon.

(Very) basic ideas

[Alexei Shekochikhin 2010]

Positive buoyancy?

Dense, gravity-driven, miscible jet?

Flow instability?

Fumer tue

Fumer peut entraîner une mort lente et douloureuse
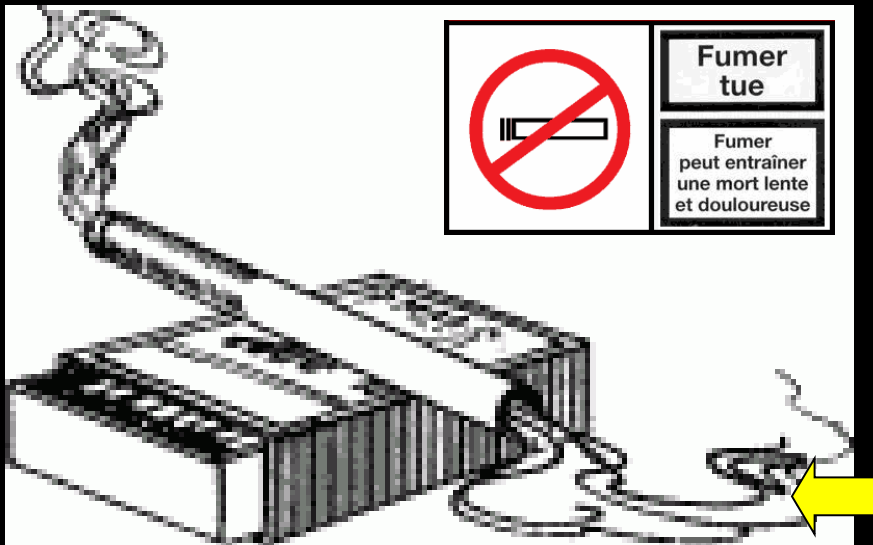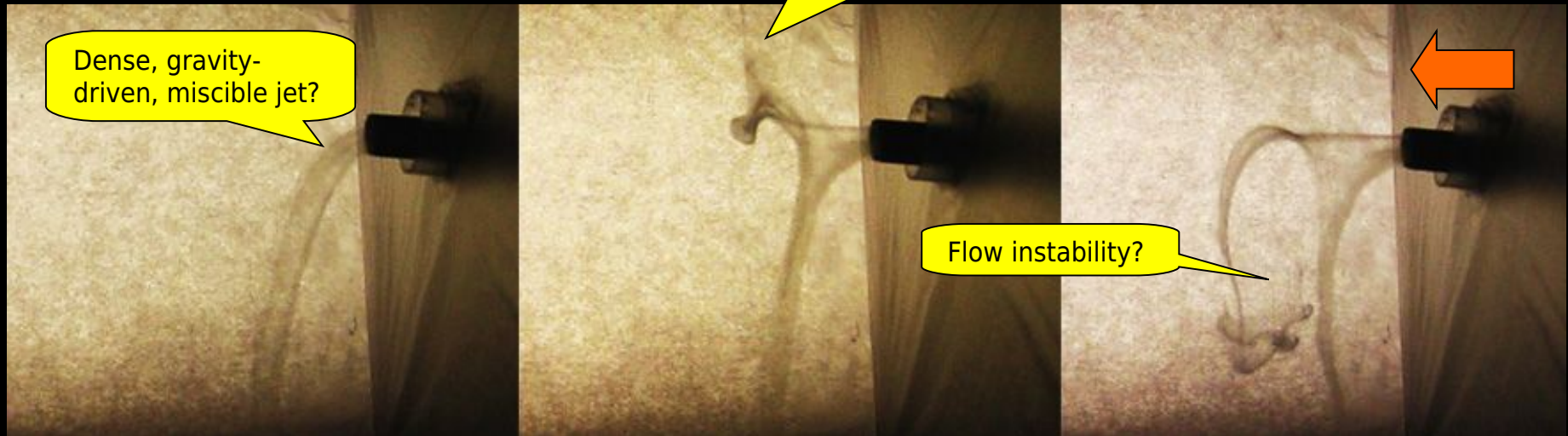
Smoke particles are unlikely to move independently from the surrounding air (why?) :-)

There should be a physical mechanism, like pressure difference, that drives air inside the jar :-)

How to identify and validate the physics behind the effect?

In cigarettes without filter, smoke shows positive buoyancy near the lit end, but negative buoyancy at the open end. Is this effect relevant?

[Перельман: Занимательная физика]

Background reading

- Поучительная папироса // Я. И. Перельман. Занимательная физика. Кн. 1. — М.: Наука, 1979, http://hf-epr.sitesled.com/library/per13.htm, http://www.biblio.nhat-nam.ru/Zanimatelnaya_fizika_1.pdf
- Hookah Bubbles Part II (youtube, from sunsetseeker, January 05, 2008), http://www.youtube.com/watch?v=89Yqx4hd1lw
- Wikipedia: Hagen-Poiseuille equation, http://en.wikipedia.org/wiki/Hagen%E2%80%93Poiseuille_equation
- Wikipedia: Nusselt number, http://en.wikipedia.org/wiki/Nusselt_number
- Wikipedia: Péclet number, http://en.wikipedia.org/wiki/P%C3%A9clet_number
- Wikipedia: Smoke, http://en.wikipedia.org/wiki/Smoke
- Wikipedia: Convection, http://en.wikipedia.org/wiki/Convection
- J. S. Turner. Jets and plumes with negative or reversing buoyancy. J. Fluid Mech. 26, 779 (1966)
- R. A. Seban, M. M. Behnia, and K. E. Abreau. Temperatures in a heated air jet discharged downward. Int. J. Heat Mass Transfer 21, 1453 (1978)
- R. W. Cresswell and R. T. Szczepura. Experimental investigation into a turbulent jet with negative buoyancy. Phys. Fluids A 5, 2865 (1993)
- Maxime Nicolas. Experimental study of gravity-driven dense suspension jets. Phys. Fluids 14, 10, 3570-3576 (2002), http://iusti.polytech.univ-mrs.fr/~nicolas/publiperso/POFJets02.pdf
- P. Philippe, C. Raufaste, P. Kurowski, and P. Petitjeans. Penetration of a negatively buoyant jet in a miscible liquid. Phys. Fluids 17, 053601 (2005), http://www.pmmh.espci.fr/~phil/Articles/art_45.pdf
- Florent Pignatel, Maxime Nicolas, Élisabeth Guazzelli, and David Saintillan. Falling jets of particles in viscous fluids. Phys. Fluids 21, 123303 (2009), http://mechse.illinois.edu/research/dstn/publications_files/suspensionjets.pdf

Background reading

- J. M. Nitsche and G. K. Batchelor. Break-up of a falling cloud containing dispersed particles. J. Fluid Mech. 340, 161 (1997)
- L. Pantzlaff and R. M. Lueptow. Transient positively and negatively buoyant turbulent rounds jets. Exp. Fluids 27, 117-125 (1999)
- P. D. Friedman and J. Katz. The flow and mixing mechanisms caused by the impingement of an immiscible interface with a vertical jet. Phys. Fluids 11, 2598 (1999)
- Alessandra Cavalletti. Impact of vertical, turbulent, planar, negatively buoyant jet with rigid horizontal bottom boundary. J. Hydraulic Eng. 129, 1, 54-62 (2003)
- W. D. Baines, A. F. Corriveau, and T. J. Reedman. Turbulent fountains in a closed chamber. J. Fluid Mech. 255, 621-646 (1993)
- W. D. Baines, J. S. Turner, I. H. Campbell. Turbulent fountains in an open chamber. J. Fluid Mech. 212, 557-559 (1990)
- O. G. Martynenko and V. N. Korovkin. Flow and heat transfer in round vertical buoyant jets. Int. J. Heat Mass Transfer 37, 51-58 (1994)
- G. Machu, W. Meile, L. C. Nitsche, and U. Schaflinger. Coalescence, torus formation and break-up of sedimenting clouds: Experiments and computer simulations. J. Fluid Mech. 447, 299 (2001)
- B. Metzger, M. Nicolas, and É. Guazzelli. Falling clouds of particles in viscous fluids. J. Fluid Mech. 580, 283 (2007)

Key questions

- Above all, what is the basic mechanism that drives the smoke into the jar? What is the ratio between the "amounts" or convection-driven smoke flowing from the open end of the tube and the smoke flowing into the jar?
- What changes, if the jar is not closed hermetically?
- How to measure the properties of the smoke stream (flow lines and velocities? temperature fields? pressure fields? density or viscosity?)
- The direction of the flow depends on the average density of fluid, which is determined by an interplay between density of solid smoke particles and the density of air. What conclusions can be drawn from known gas temperatures and viscosities, and concentration of particles?
- What are the magnitudes of the Reynolds' or Nusselt numbers for the observed flows? Is the flow laminar or turbulent; negatively or positively buoyant; miscible or not? Are there particular, critical conditions that qualitatively change the geometry of the flow?
- How relevant is the Hagen-Poiseuille equation to describe the flow inside the tube?
- How does the effect depend on the geometry of the tube (length? diameter? specific combustion heat and the amount of smoke produced?)
- How does the effect depend on the geometry of the jar (total internal volume?)
- How to best visualize the phenomenon? What information about the system can be retrieved from the flow lines? Is there a contact-free (optical?) method to determine the concentration of smoke particles in a particular point?
- How reproducible is the overall effect? Is there a correlation between the instant combustion rate and the immediate parameters of the stream?
- What happens, if the tube is lit from the end inside the tube? What are your conclusions on the problem?

Problem No. 17 "Vikings"

According to a legend, Vikings were able to navigate in an ocean even during overcast (dull) weather using tourmaline crystals. Study how it is possible to navigate using a polarizing material. What is the accuracy of the method?
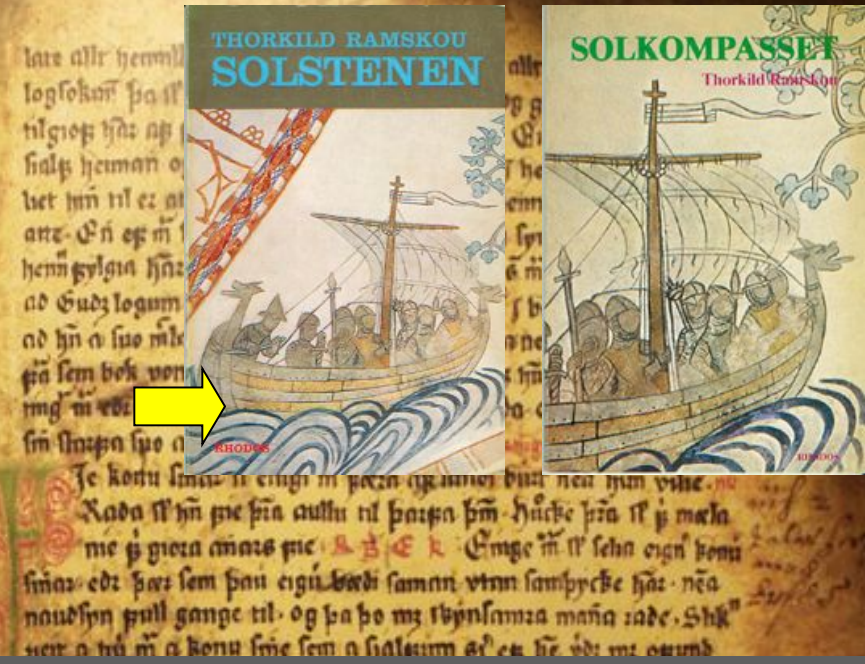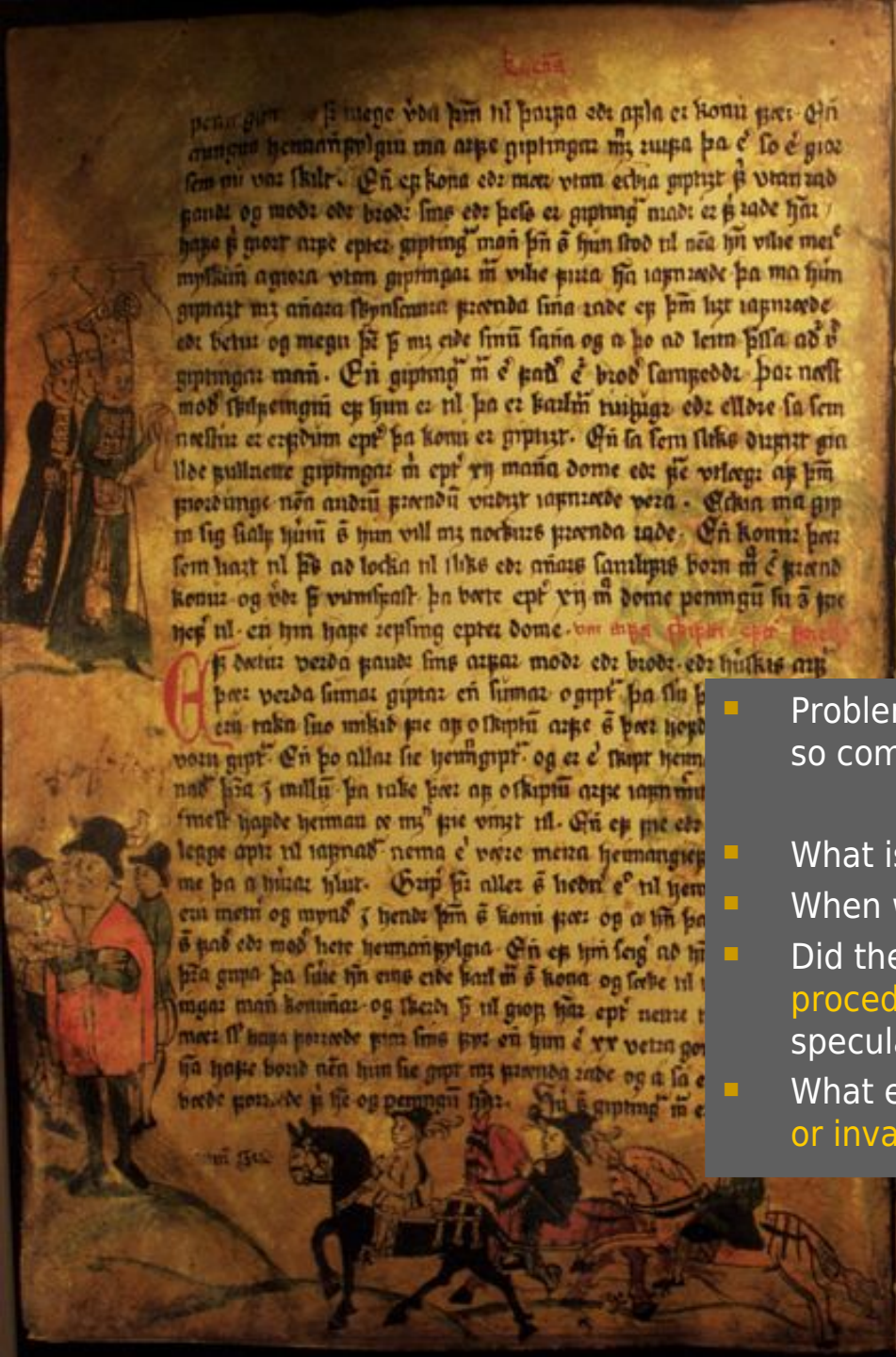
- Problems that required knowledge in humanities were not so common at YPTs after 1980s :-)

- What is the primary source of the "legend"?
- When was it written: at the times of Vikings, or recently?
- Did the original source contain a detailed description of the procedure used by Vikings, or just suggestions and speculations?
- What earlier historical research was undergone to validate or invalidate these "legends"?

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SOLSTRÅLER FRA HORISONTEN

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re og supplere vore skolekundskaber i
fysik. Lys er som bekendt en bølgebevæ-
gelse; elementer i lysstrålen svinger om-
kring en ligevægtsstilling, og bevægelsen
foregår på tværs af stråleretningen. I al-
mindelighed foregår udsvingene i alle
retninger ud fra strålen, men under vis-
se omstændigheder kan lyset blive pola-

et skylag, som dog ikke dækker hele
himlen, hvis det er tilfældet, er solsten-
en til ringe nytte. Manden nede på jorden
kan ikke se solen for skyerne, men nok
den blå himmel lige over sit hoved. Når
han ser lodret op mod den, rammes hans
øje af det polariserede lys, som sollyset
har fremkaldt i atmosfæren. Holder han
solstenen, polarisationsfilteret, for øjet
og drejer den om en lodret akse som vist
på billedet, vil han opleve det mærkelige,
at stenen i en bestemt stilling er lys og
gennemskinnelig, mens den, hvis han der-
efter drejer den en kvart omgang, bliver

en til den store lysgiver, o
skjulte sig bag skyer.
» - og han så dér, hvor
fra stenen - «. Nu forstår vi
skriveren mener. Kong Olav
stenen indtil den stilling, hvo
lede, det vil sige blev lys og
nelig. Fortællingen om sol
altid har været mødt med ske
været genstand for mange fo
bliver pludselig klar og trovær
målet er nu blot, hvilke krys
boerne for ca 1000 år siden
polarisationsfiltre. Mulighed
mange, for de nødvendige ege
des kun hos ganske få min
bedst kendte er dobbelt spa
des i Island, men for nordma
gurd og Olav har der være
liggende emner: d i c r o i t :
lariserende lys ses lysere e
blå, og andalucit, som
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Herjolfsson indicates. Immediately after land disappeared, the following sequence of events is narrated:[69]

Then the wind dropped and they were beset by winds from the north and fog; for many days they did not know where they were sailing. After that they saw the sun and could take their bearings.

In *Grænlendinga Saga* this combination of fog and wind is termed *hafvilla*;[70] and we now know that when conditions are such as to cause refraction the mirage produced is often followed by fog.[71] The saga then paints a plausible picture of what anyone blown off course and with no instruments to guide them would do – look to the sun's position. If the zenith was higher in the sky than it was in Iceland, Bjarni would conclude that he was much too far south to be in the area of Greenland. Had Bjarni[72] possessed a sun-compass, or rather had the composer of the saga known about them, it is unlikely that he would have been portrayed as relying on dead-reckoning to sail out of a tight spot. There is also no possibility that Bjarni, or anyone else lost in fog at sea for that matter, used a *sólarsteinn* or sunstone. It has been argued that this entirely fictional contrivance acted as a prism allowing polarised light to filter through, thereby indicating the sun's position.[73]

However, experiments with Icelandic felspar have proved that this does not work. Moreover, literary scholars agree that references to *sólarsteinar* only appear after 1200 and probably refer to a 'burning-glass' and not a navigational instrument.[74] Even attempts to calculate approximate latitude by reference to the sun's elevation above the rim of the horizon, using such simple tools as a notched stick or even one's hand, knuckles or thumb, might result in mishap where the true horizon was obscured by fog and one's position estimated on the basis of a false sighting.

[69] *The Saga of the Greenlanders*, trans. K. Kunz. In *The Sagas of Icelanders*, see note 2 above, p. 637.

[70] G. J. Marcus, *Hafvilla: a note on Norse navigation. Speculum*, Vol. 30, 1955, pp. 601–5; Marcus, *Conquest*, pp. 59–62, 106–7. Other instances of *hafvilla* are encountered in *Landnámabók* and *Njál's Saga*.

[71] *Arctic Pilot*, p. 18.

[72] Or, for that matter, Olaf Peacock or Orn, when they too suffered 'sea-bewilderment' in the episode described above, p. 328.

[73] T. Ramskou, *Solstenen. Skalk*, 2, 1967, pp. 16–17.

[74] P. Foote, *Icelandic sólarsteinn and the medieval background*. In *Aurvandilstá*, see note 25 above, pp. 140–54.
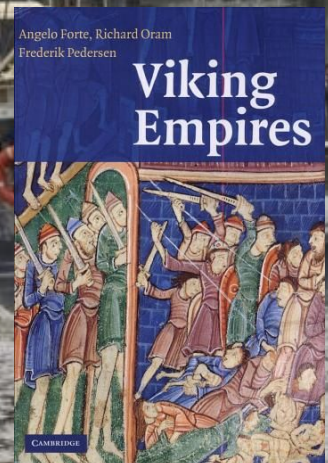
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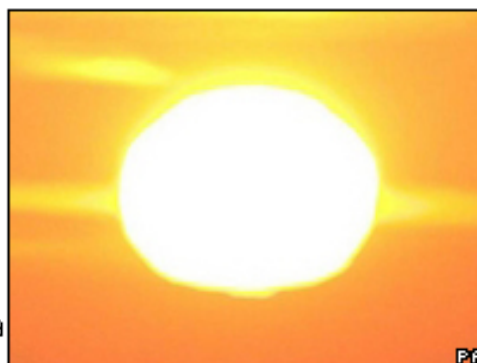# Crystals 'helped Viking sailors'

Vikings may have used a special crystal called a sunstone to help navigate the seas even when the sun was obscured by fog or cloud, a study has suggested.

The sun was not necessary for Vikings to navigate, say researchers

Researchers from Hungary ran a test with sunstones in the Arctic ocean, and found that the crystals can reveal the sun's position even in bad weather.

This would have allowed the Vikings to navigate successfully, they say.

The sunstone theory has been around for 40 years, but some academics have treated it with extreme scepticism.

Researcher Gabor Horvath from Eotvos University in Budapest led a team that spent a month recording polarisation - how rays of light display different properties in different directions - in the Arctic.

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Background reading

- Thorkild Ramskou. Solstenen. Skalk, Nr. 2, 16-17 (1967)
- Thorkild Ramskou. Solstenen, Primitiv Navigation i Norden før Kompasse (Rhodos, København, 1969)
- Thorkild Ramskou. Solkompasset (Rhodos, København, 1982)
- Ramón Hegedüs, Susanne Åkesson, Rüdiger Wehner and Gábor Horváth. Could Vikings have navigated under foggy and cloudy conditions by skylight polarization? On the atmospheric optical prerequisites of polarimetric Viking navigation under foggy and cloudy skies. Proc. R. Soc. A 463, 1081-1095 (2007)
- Ramón Hegedüs, Susanne Åkesson, and Gábor Horváth. Polarization patterns of thick clouds: overcast skies have distribution of the angle of polarization similar to that of clear skies. J. Opt. Soc. Am. A 24, 8, 2347-2356 (2007)
- Ramón Hegedüs, András Barta, Balázs Bernáth, Victor Benno Meyer-Rochow, and Gábor Horváth. Imaging polarimetry of forest canopies: how the azimuth direction of the sun, occluded by vegetation, can be assessed from the polarization pattern of the sunlit foliage. Applied Optics 46, 23, 6019-6032 (2007)
- András Barta, Gábor Horváth, and Victor Benno Meyer-Rochow. Psychophysical study of the visual sun location in pictures of cloudy and twilight skies inspired by Viking navigation. J. Opt. Soc. Am. A 22, 6, 1023-1034 (2005)
- Corey Binns. How Vikings might have navigated on cloudy days (livescience.com, March 2, 2007), http://www.livescience.com/history/070302_viking_navigation.html
- Rachel Muheim, Susanne Åkesson, and John B. Phillips. Magnetic compass of migratory Savannah sparrows is calibrated by skylight polarization at sunrise and sunset. J. Ornithology 148, 485 (2007)

Background reading

- Viking navigation hypothesis under foggy and cloudy skies requires more light (physorg.com, February 27, 2007), www.physorg.com/pdf91798327.pdf
- Leif K. Karlsen. Secrets of the Viking Navigators (One Earth Press, 2003), http://www.oneearthpress.com/
- Dirk Jan Willem Meiers. The Viking Sunstone: Is the legend of the Sun-Stone true? http://www.xs4all.nl/~dmeijers/artikelen/viking/polarized.htm, http://www.polarization.com/viking/viking.html
- Curt Roslund and Claes Beckman. Disputing Viking navigation by polarized skylight. App. Optics 33, 21, 4754 (1994)
- Angelo Forte, Richard Oram, Frederik Pedersen. Viking Empires (Cambridge University Press, 2005), p. 349, http://books.google.com/books?id=_vEd859jvk0C&
- Sky Compass. Review of Scientific Instruments, 20, 46 (1949)
- H. LaFey. The Vikings. National Geographic 137, 528 (1970)
- R. Wehner. Polarized-light navigation by insects. Sci. Am. 31, 1, 106 (1976)
- Bradley E. Schaefer. Vikings and polarization sundials. Sky & Telescope, May 1997, p. 91
- Kane Usher, Peter Ridley, Peter Corke. A camera as a polarized light compass: preliminary experiments. Proc. 2001 Australian Conf. on Robotics and Automation (Sydney, November 14-15, 2001), http://www.araa.asn.au/acra/acra2001/Papers/Usher.pdf
- The fabled Viking sunstone (nordskip.com), http://www.nordskip.com/vikingcompass.html, http://www.nordskip.com/vdetail.html
- Leif K. Karlsen: Secrets of the Viking navigators (nordskip.com), http://www.nordskip.com/vkarlsen.html
- Leif K. Karlsen. Viking navigation using the sunstone, polarized light and the horizon board. Navigation notes 93, 5-8 (2006), http://www.oneearthpress.com/pdf/nav_notes.pdf
- Oscar Noel and Sue Ann Bowling. Polar navigation and the sky compass, Article #865 (Alaska Science Forum, March 21, 1988), http://www.gi.alaska.edu/ScienceForum/ASF8/865.html

Key questions

- The problem has been quite profoundly investigated by Horváth *et al.*, and other groups. How should we approach the task and what aspects to investigate, in order not to repeat earlier work and seriously contribute to the understanding of the tricky problem?
- Above all, what is your conclusion on the problem? Aside from a strictly physical analysis of navigation with polarizers,
  - what are the overall chances that Vikings were indeed using such devices?
  - what arguments did the initial proponents of the hypothesis use to validate such an idea?

what are its x, y, and z componetits iii to

(b) Compute $(\hat{\mathbf{r}} \cdot \nabla)\hat{\mathbf{r}}$, where $\hat{\mathbf{r}}$ is the uni

(c) For the functions in Prob. 1.15, evalu

Problem 1.22 (For masochists only.) P the definition of $(\mathbf{A} \cdot \nabla)\mathbf{B}$.

Problem 1.23 Derive the three quotien

Problem 1.24

The ultimate response to all "What for?"–questions:

" If we knew what we were doing,
it wouldn't be called research! "

Albert Einstein

Don't Drink and Derive.

$$\frac{1}{c^2}\frac{\partial^2 u}{\partial x^2}=0 \qquad E=4\pi\varepsilon_0\,\frac{q\hat{r}}{r^2} \qquad \vec{p}=\bar{m}v$$

$$G\frac{m_1 m_2 m_3}{r^3} \qquad f(x)=\int_{-\infty}^{\infty} dk\, g(k)\, e^{ikx} \qquad \nabla\cdot E=\frac{1}{\mu_0}\rho$$

$$\nabla\cdot B=4\pi$$

$$=I-R \qquad E=mc^3 \qquad p=\frac{mv}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$-\frac{\hbar^2}{2m}\nabla\psi+V(r)=i\hbar\frac{\partial^2\psi}{\partial t^2} \qquad \frac{\partial L}{\partial p_k}=q_k \qquad PV=n+R+T$$

$$n\lambda=2d\tan\theta \qquad n_a\sin\varphi_b=n_b\sin\varphi_a$$

$$F=\sqrt{ma} \qquad v=\dddot{x} \qquad x=\frac{1}{2}at^2+v_0 t+x_0 t^2$$

To work towards results?

- Nobody needs an infinitely perfect report in an infinite time!

- If you cannot solve the entire problem, decide what is really necessary and solve a partial problem

- If you can solve the entire problem, nevertheless decide what partial case is sufficient, and your solution will be much better

- Be brave in what you do, but always reserve a great degree of scientific skepticism!

- Procrastination is definitely a risk :-)

Feynman: to be self-confident?

- "I've very often made mistakes in my physics by thinking the theory isn't as good as it really is, thinking that there are lots of complications that are going to spoil it

- — an attitude that anything can happen, in spite of what you're pretty sure should happen."

R.P. Feynman. Surely You're Joking, Mr. Feynman (Norton, New York, NY, 1985)
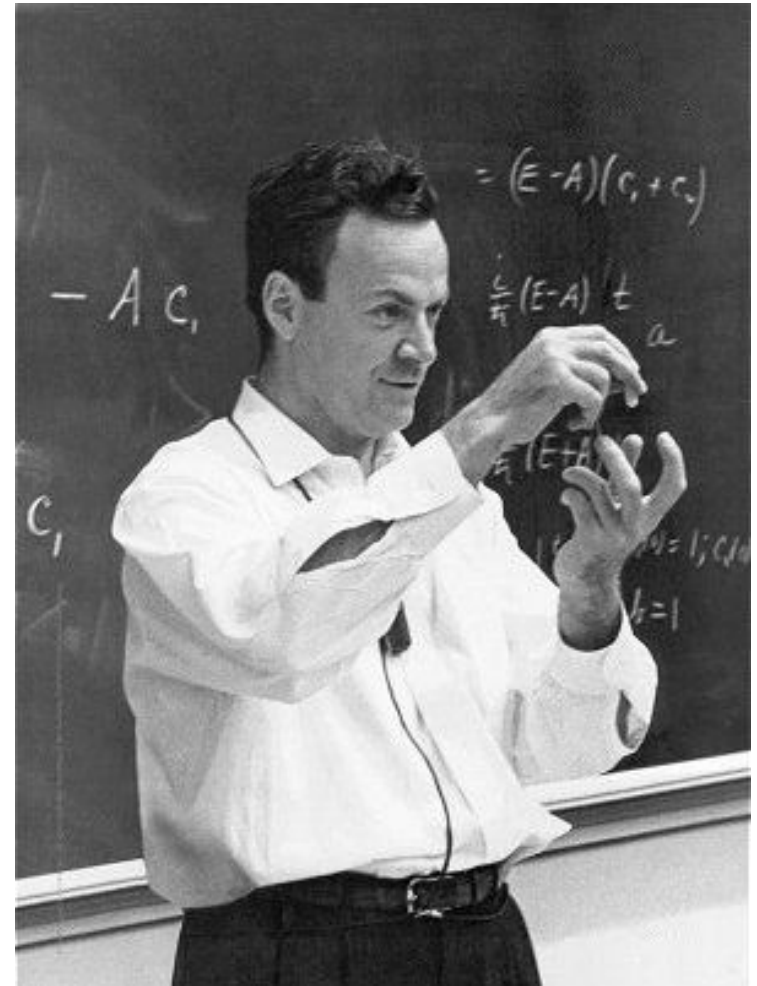
Preparation to 24th IYPT' 2011:

references, questions and advices

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Tiki Torch Triptych, by Phineas X. Jones, is used on the cover with kind permission

Call for cooperation

- If you are interested in the idea behind the kit — to structure the earlier knowledge about the problems and to encourage students to contrast their personal contribution from this knowledge — and you are interested to join the project, your cooperation is welcome
- If several contributors start bringing together the kit for 2012, a good draft can be ready within weeks after the problems are selected
- It will be of benefit for everybody,
    - students and team leaders, who will have an early reference (providing a first impetus to the work) and a strong warning that IYPT is all about appropriate, novel research, and not "re-inventing the wheel"
    - jurors, who will have a brief, informal auxiliary material, possibly making them more skeptical and objective about the presentations
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    - and also the author(s) of the kit, who can rapidly acquire some competence for future activities and have a great learning experience