# THE 13TH IYPT

### Budapest (Hungary), July 8th – 15th, 2000

# *Preparation*

## The problems for the 13th IYPT

**1. Invent by yourself**
Suggest a contact-free method for the measurement of the surface tension coefficient of water. Make an estimation of the accuracy of the method.

**2. Tuning fork**
A tuning fork with a resonant frequency of about 100 Hz is struck and held horizontally, so that its prongs oscillate up and down. A drop of water is placed on the surface of the upper prong. During the oscillation of the tuning fork standing waves appear on the surface of the drop and change with time. Explain the observed phenomena.

**3. Plasma**
Investigate the electrical conductivity of the flame of 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 150V.

**4. Splash of water**
Measure the height reached by splashes of water when a spherical body is dropped into water. Find a relationship between the height of the splashes, the height from which the body is dropped, and other relevant parameters.

**5. Sparkling water**
Bubbles in a glass of sparkling water adhere to the walls of the glass at different heights. Find a relationship between the average size of the bubble and their height on the side of the glass.

**6. Transmission of signals**
Using a bulb construct the optimum transmitter of signals without any modulation of the light beam between the transmitter and the receiver. Investigate the parameters of your device. The quality of the device is defined by the product of the information rate (bits/sec) and distance between transmitter and receiver.

**7. Merry-go-round**
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?

**8. Freezing drop**
Drops of melted lead or tin fall from some height into a deep vessel filled with water. Describe and explain the shape of the frozen drops as a function of height of fall.

**9. Radioactivity**
Use efficient methods to collect as much radioactive material as you can in a room. Measure the half-life of the material you have collected.

**10. Liquid fingers**
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.

**11. Throwing stone**
A student wants to throw a stone so that it reaches the greatest distance possible. Find the optimum mass of the stone that should be used.

**12. Tearing paper**
Tear a sheet of paper and investigate the path along which the paper tears.

**13. Rolling can**
A can partially filled with water rolls down an inclined plane. Investigate its motion.

**14. Illumination**
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.

**15. Cooling water**
Two identical open glasses, filled with hot and warm water, respectively, begin to cool under normal room conditions. Is it possible that the glass filled with hot water will ever reach a lower temperature than the glass filled with warm water? Make an experiment and explain the result.

**16. Coloured sand**
Allow a mixture of differently coloured, granular materials to trickle into a transparent, narrow container. The materials build up distinct bands. Investigate and explain this phenomenon.

**17. A strange sound**
Pour hot water into a cup containing some cappuccino or chocolate powder. Stir slightly. If you then knock the bottom of the cup with a teaspoon you will hear a sound of low pitch. Study how the pitch changes when you continue knocking. Explain the phenomenon.[4]

# General comments on the problems

The problems for the 13$^{th}$ IYPT are not as various as the problems for the 12$^{th}$ IYPT were. Lots of them concern similar physic disciplines (in particular: fluid dynamics, solid state physics,...).
The division into the three groups mentioned is not so easy. There is only one problem concerning an “every-day-life”-effect: no. 17 “A strange sound”: I recommend all people who often drink cappuccino or hot chocolate to try it. I’m sure you can surprise some others with the strange effect.

Lots of the other problems require basic science knowledge in order to be completely understood.
Even when they do not seem so interesting to the layman, some of them are quite fascinating.

[4] http://metal.elte.hu/~iypt2000/Problems.html

In addition I have to mention that I consider the problems for the 13th IYPT more interesting, but also more difficult than the problems of the 12th IYPT, which is perhaps due to the fact that our preparations work was much more interesting and organised but also more difficult because of our experiences.

If I had to mention 3 favourite problems I would say: no. 6 “Transmission of signals”, no. 3 “Plasma”, no. 7 “Merry-go-round” (in that order).

# Chronology of the preparations work

It was on the 28 of October 1999 when we downloaded the problems of the 13th IYPT. That time we wanted to be more organised, with weekly meetings, and with the goal to prepare an efficient IYPT report. We had learned from our mistakes from the previous year.

From October until Christmas we had a weekly meeting where we did various experiments and theoretical work. After the Christmas holidays our efforts stalled a bit because we were working on an UNESCO physics project which was time-consuming.
Our teacher, however, continued to keep contact with different science institutes and experts.
The AYPT 2000 was scheduled for April 23-24. For that year 10 problems of the 17 had been preselected for the AYPT so that there was not too much work to do.
Moreover, we learned that 2 foreign teams had been invited to the AYPT (on from Italy, one from Ukraine).

So in the weeks before the AYPT we really worked hard on the final layout of our presentations. We also prepared possible arguments for our opponences and reviews, had tactical discussions and practised our presentations so that they would really impress the jury.

That year Austria could only send one team to the international competition, so if we wanted to participate in the IYPT we had to win the AYPT. Therefore we really worked hard.

In addition to that, we had one significant problem: Normally an IYPT team consists of 5 members. Unfortunately there were only 3 members left.

So each of us had more work to do than in a 5-members team, even during the Easter holidays we had to do some work.
Finally 5 teams were competing at the 2$^{nd}$ AYPT in Vienna. One from the Polgarstraße school, on from the Lycee francais, one from Italy, one from the Ukraine and our team.

There were 2 fights on the program: one selective, and one final fight. We presented two reports which were very much appreciated by the jury and succeeded in winning the 2$^{nd}$ AYPT by 20 points.
It was a great feeling that we would be able to represent our country in the IYPT again, due to our own abilities and experiences.
The other teams did not have any students from the previous year left, so the three of us were the only experienced ones.

As I have already mentioned, we were only 3 team members. So 2 students of our choice from the other teams could accompany us to Budapest, which gave them the opportunity to participate too. On the other hand we benefited from their solutions, reports and other materials as well as from the help of their teachers and colleagues.

The fact was that we had two and a half months left until the IYPT in Budapest, but not the whole time was available for preparation because of some other scheduled events and projects.
There had been 7 problems left, which had not been preselected for the AYPT. So there was still no solution to these problems and the presentations from the AYPT had to be improved. Errors which were detected during or after the competition had to be corrected.

Several meetings in Vienna were held in order to plan further activities and to compare results.
One day we also invited some professors from the Viennese university, who were jurors in the AYPT, to help us.

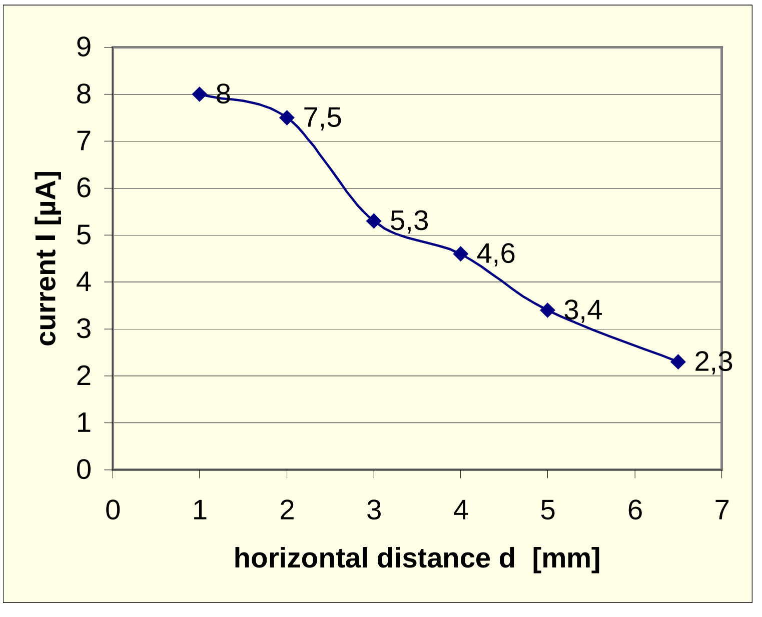
Unfortunately there was not enough time left to prepare reports for all of the problems. So we finally went to Budapest in July 2000 with 11 well-prepared presentations.
Nevertheless we felt better than the year before, because our science knowledge and our English had greatly improved, especially technical terms didn't cause troubles any more, because we got more used to "science English".

# Reports and solutions

I also want to present some of our reports from the 13th IYPT had been modified. Text had been added to substitute the oral presentation, and the layout had to be changed too, because the original report had been designed for overhead transparencies in Landscape format.

## Problem no. 3 "Plasma"

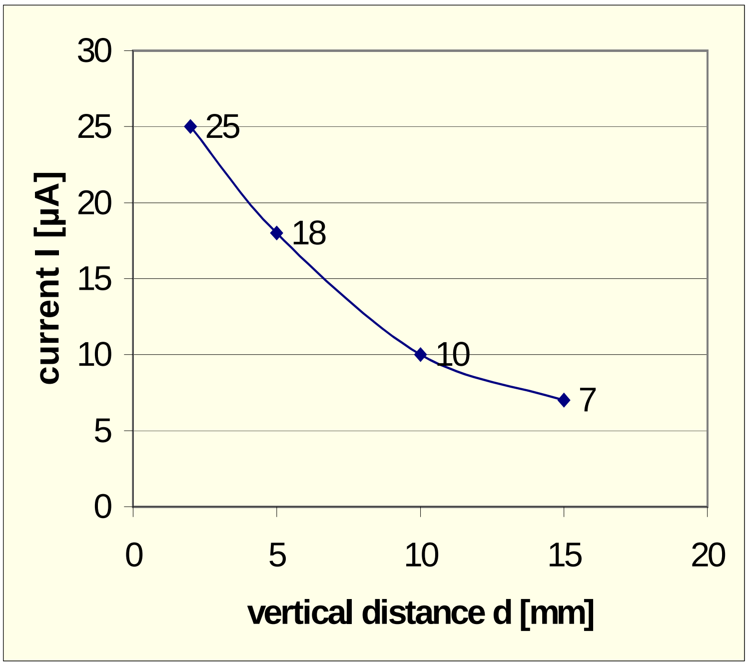
Measurements had to be done first. As an example for the results of our measurements we want to show you two diagrams. The measurements were quite difficult, because there were lots of fluctuations. So the results are only average values.
This diagram shows the dependence of the current from the voltage.




***experimental data:***

- sharp electrodes
- on the same level in the flame
- voltage: 150 V, DC

This diagram shows another example of our measurements.




***experimental data:***

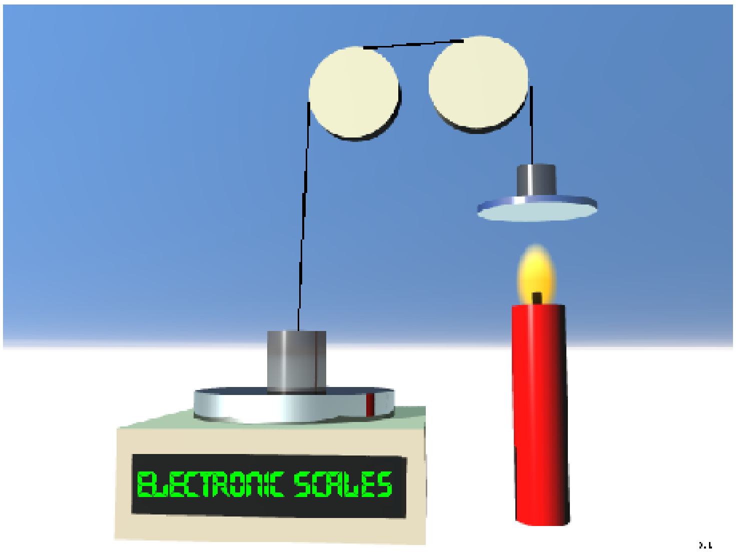
- sharp electrodes
- above each other
- Intersection: about 4 mm
- voltage: 150 V, DC

After our measurements we drew the following conclusions:

This is a chaotic system with hardly reproducible measurement results.
The problem can't be completely solved, only the influence of various parameters can be examined, such as:
the electric field (shape and arrangement of the electrodes)
the temperature
the gas flow and the composition of the gas

Now we want to show you, what we found out about the influence of these parameters.
Let's start with the gas flow:
For our research on gas flow, we "recycled" a theory and measurement results from the previous year. For those who can't remember: In the 12$^{th}$ IYPT the problem no. 13 "Gas flow" concerned the gas flow in the flame of a candle. So we now show you what we found out one year ago:

This sketch shows you, how we measured the gas flow:




left mass: 2g; right mass: 1g; connected with a circular Al – plate (in the flame: Fe – plate);Temperature measurement with Pt-100 or thermocouple

The streaming force $F_{Str}$ is an upward force on the right mass which produces an additional downward force on the electronic scales. This causes the scales to show a higher weight, so $F_{Str}$ can be calculated using this "mass difference" $\Delta m$.

With the streaming force we are able to calculate the velocity of the gas flow using this formula:

$$F_{Str} = \frac{c_w \cdot A \cdot \rho \cdot v^2}{2} \Rightarrow v = \sqrt{\frac{2 \cdot F_{Str}}{c_w \cdot A \cdot \rho}}$$

$C_w$ = 1,1 (for circular plates)
A = r².π (area of the circular plate)
$F_{Str}$ ... has been measured
ρ ... density of air: calculated (see following transparency)

Calculation of air density: using the ideal gas equation

$$p \cdot V = n \cdot R \cdot T$$

$$p \cdot V = \frac{m}{M} \cdot R \cdot T$$

$$p \cdot M = \frac{m}{V} \cdot R \cdot T$$

$$p \cdot M = \rho \cdot R \cdot T$$

$$\rho = \frac{p \cdot M}{R \cdot T}$$

| | |
|---|---|
| p | pressure [Pa] |
| V | volume [m³] |
| n | number of moles |
| R | gas constant (= 8,31) [ J / (K . mol) ] |
| T | temperature [K] |
| M | molecular weight |
| ρ | density [kg/m³] |

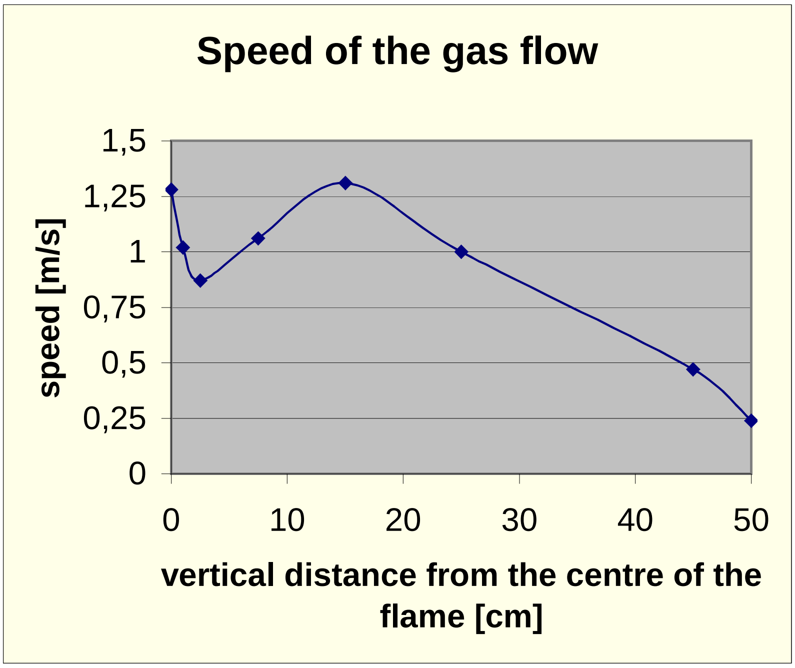
**calculation of the molecular weight M:**
values from literature: air at 0°C, 1 bar: $\rho$ = 1,293 [kg/m³]

$$M = \frac{\rho \cdot R \cdot T_0}{p_0} = \frac{1{,}293 \cdot 8{,}31 \cdot 273{,}15}{10^5}$$

$$M = 0{,}02935 [kg]$$ ($\rho$ [kg/m³] → M [kg])

---

This diagram finally shows the result of the gas flow measurements: Velocity of the flow versus the vertical distance from the flame:




Furthermore we considered some theory about plasma. Useful statements can only be given about a balance plasma. For a balance plasma, 3 distributions have to be fulfilled:

- The Boltzmann-,
- the Maxwell-,
- and the Saha-distribution.

The following formula is the Maxwell distribution. It indicates how many molecules have a distinct velocity. It is possible to calculate the fraction of molecules for each velocity v.

$$N(v) = 4\pi \; N \left( \frac{m_M}{2\pi \; k \; T} \right)^{\frac{3}{2}} v^2 \cdot e^{-\frac{m_M v^2}{2kT}}$$

N...number of molecules
k...Boltzmann constant (≈1,38.10$^{-23}$ [J/K])
$m_M$...mass of one molecule
T...temperature [K]

We wanted to find out, how many molecules are ionised. In order to calculate the minimum velocity for ionisation through hits, we set the ionisation energy equal to the kinetic energy of a molecule.

$$E_i = \frac{m_M \cdot {v_{min}}^2}{2}$$

After having calculated the minimum velocity, we used the Maxwell distribution to calculate the fraction x of molecules which are faster than the minimum speed.

$$x = 4\pi \left( \frac{m_M}{2\pi\ k\ T} \right)^{\frac{3}{2}} \int_{v_{min}}^{\infty} v^2 \cdot e^{-\frac{m_M v^2}{2kT}}\, dv$$

It is possible to calculate this for each kind of molecules in the plasma. Here are two results for example:

results: e.g. for $O_2$: $x \approx 3.10^{-64}$; for $N_2$: $x \approx 9.10^{-91}$

As you can see the fraction of ionised molecules is so small that it is possible to neglect it.

# The Saha distribution:

The Saha equation indicates the ionisation balance between the electrons and the ions versus neutral particles:

$$\frac{N_e^- \cdot N_i^+}{N}$$

$$S = \frac{(2 \cdot \pi \cdot m_e)^{\frac{3}{2}}}{h^3} \cdot (k \cdot T)^{\frac{5}{2}} \cdot e^{-\frac{E_i}{k \cdot T}}$$

$m_e$....mass of the electron
h......Planck constant
k.......Boltzmann constant
T.......temperature
$E_i$......ionisation energy

Also this equation proofs that there are actually no ions in the plasma.

# Influence of the electric field:

The electric field causes electrons to drift through the plasma with a current density j:

$$j = N_e \cdot e \cdot v_d$$

Moreover we used some formulas which we found in literature.

$$j = \sigma \cdot E \qquad v_d = \mu \cdot E \qquad \lambda_e = v_e \cdot \tau$$

$$v_d = \frac{e}{m_e} \cdot \tau \cdot E \qquad v_e = \sqrt{\frac{8 \cdot k \cdot T}{\pi \cdot m_e}}$$

$N_e$...number of electrons
e....elementary charge
$v_d$...drifting speed
E....electric field strength
$m_e$..mass of the electron
$\tau$.....average time between 2 hits
$\sigma$....conductivity
$\mu$....mobility of the electrons
$\lambda_e$....free distance between 2 hits
$v_e$....average speed of the electrons (Maxwell distribution)
k.....Boltzmann constant
T.....temperature

Using the shown formula, we can proof that the conductivity is proportional to one divided by squareroot of the mass.

$$j = N_e \cdot e \cdot \mu_e \cdot E = \sigma \cdot E$$

$$\Rightarrow \sigma = \frac{1}{2}\sqrt{\frac{\pi}{2}} \cdot \frac{e^2}{\sqrt{m_e \cdot k \cdot T}} \cdot N_e \cdot \lambda_e$$

$$\Rightarrow \sigma \sim \frac{1}{\sqrt{m}}$$

By taking an element with an average mass from the periodic system of the elements we can show that the share of ions of the current is < 0,4 %.
So we can restrict ourselves to the consideration of drifting electrons only.

The Richardson-Dushman equation indicates, how many electrons are emitted by the electrodes.

$$j = A \cdot T^2 \cdot e^{-\frac{W_A}{k \cdot T}}$$

$$A = \frac{4\pi \cdot m \cdot k \cdot T}{h^3}$$

$W_A$...work function
k......Boltzmann constant
T......Temperature
h......Planck constant
m.....rest mass of the electron

The Richardson-Dushman equation shows only the influence of the temperature and does not consider the point effect!

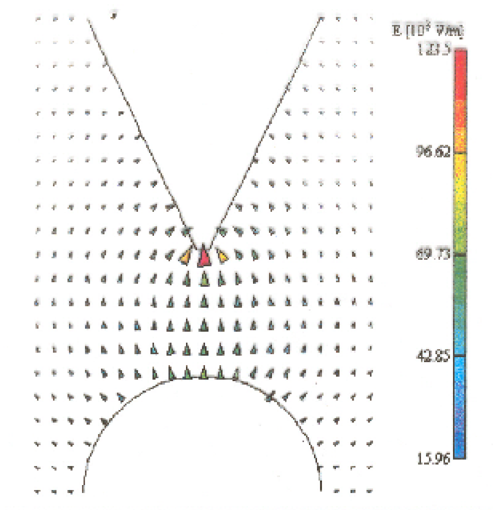
The electric field also causes the electrodes to emit electrons, as it is indicated by the Fowler-Nordheim equation.

$$E = \frac{F}{Q} = \frac{F}{e_c}$$

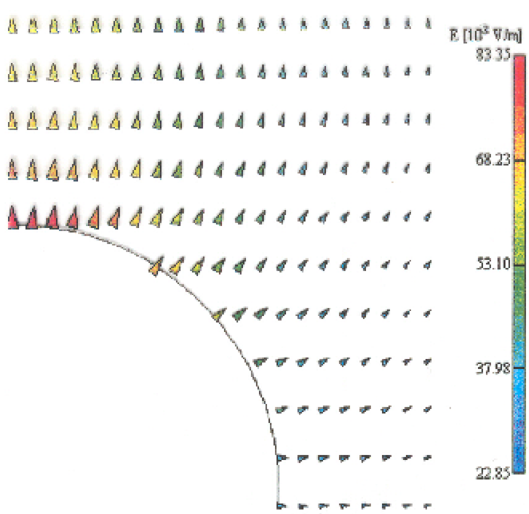
$$j \sim E^2 \cdot e^{-\frac{1}{E}}$$

E....electric field strength
F....force
Q....charge
$e_c$...elementary charge
j.....current density

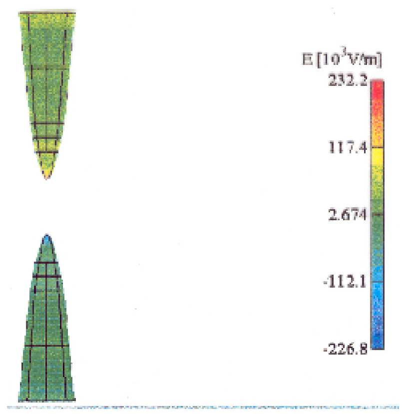
It shows that the current density is proportional to the electric field strength squared times Euler's number to the minus one divided by the field strength.
To determine the electric field strength we made a computer simulation. The following plots shall give you an idea how the field depends on the shape and arrangement of the electrodes.



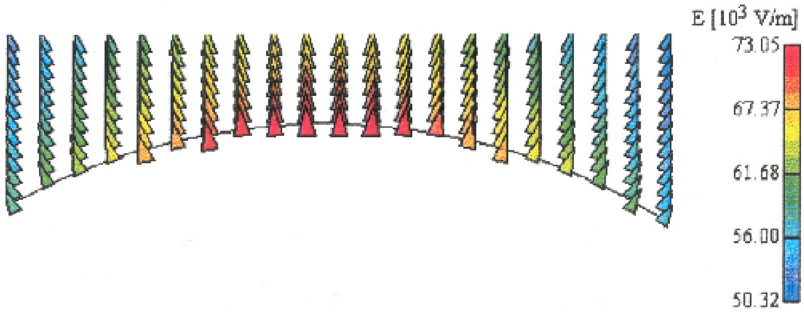

Electric field between a spherical and a point electrode




Field between 2 spherical electrodes (quarter of the symmetry)




Potential distribution on the surface of 2 needle electrodes




Field on the surface of a spherical electrode

In conclusion the following things have to be said: The connection between our experiments and our theory is not possible. The current is determined by so many parameters which correlate so much that it is not possible to measure the dependence of the current from one single parameter. Therefore there can be no real connection between theory and experiments. Moreover, the phenomenon is much too complex so that there can be no final solution formula which describes the behaviour of the current.

# Problem no. 7 "Merry-go-round"

## Description of the experiment:

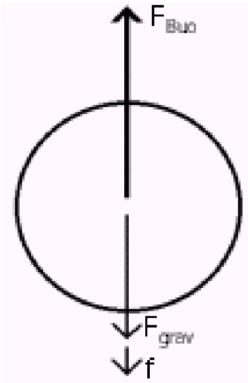
We filled a glass with water, with r = 8 cm and h = 20 cm. The ball was made of tin foil filled with a small amount of air and a very small piece of a magnetic material. With a big magnet we could hold the ball down on the bottom of the vessel. In our case the rotating disks were turntables.

| | $\omega=0$ | $\omega=\pi s^{-1}$ | $\omega=1,5\pi s^{-1}$ |
|---|---|---|---|
| Ball 1 | 4s | 15s | 30s |
| Ball 2 | 8s | 30s | 60s |

Here we have the time the ball needs to reach the surface at different angular velocities. We can see that the velocity of the ball on the rotating disk is nearly 10 times slower than on the stationary disk.

# Theory (without rotation):

First we considered all the acting forces:




$$F_{grav} = \rho_{ball} \cdot V \cdot g$$

$$F_{Buo} = \rho_{wat} \cdot V \cdot g$$

$$f = 6 \cdot \pi \cdot \eta \cdot r \cdot v$$

(formula of Stokes)

Newton's law: $\rho_{wat} \cdot V \cdot g - \rho_{ball} \cdot V \cdot g - 6 \cdot \pi \cdot \eta \cdot r \cdot v = m_{ball} \cdot \frac{dv}{dt}$

The forces which act on the ball are the gravitational force, the buoyancy force and the friction force. There are two possibilities for the friction force: the flow resistance force or Stoke's friction force.
Trying to find out which one we have to use we calculated the Reynolds's number. The calculated Reynolds number was approximately 150. So the flow pattern is definitely laminar. In a laminar flow the flow resistance is characterised by Stoke's law.
By using Newton's law we summed up all the acting forces and set them equal to mass times acceleration.
We reworded the formula so that the velocity is now shown explicit.

$$v = \frac{2 \cdot r^2 \cdot g \cdot \Delta\rho \cdot (1 - e^{\frac{-9 \cdot \eta \cdot t}{2 \cdot r^2 \cdot g \cdot \rho_{wat}}})}{9 \cdot \eta} \qquad \Delta\rho = \rho_{wat} - \rho_{ball}$$

You can see that for a very large, nearly infinite time t, the velocity becomes constant because the exponential function converges to 0.
So the formula for this limit speed is

$$V_{\lim} = \frac{2 \cdot r^2 \cdot g \cdot \Delta\rho}{9 \cdot \eta}$$

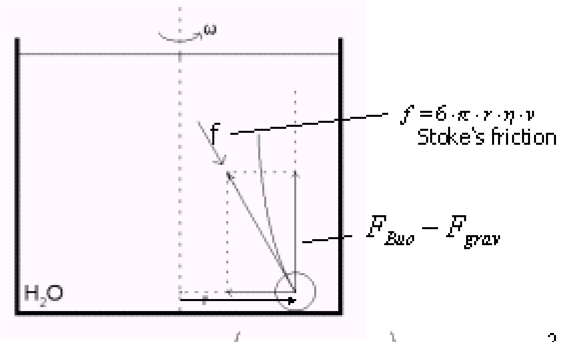
In order to keep the limit speed small we had three possibilities:

- **Have a very little $\Delta\rho$ in water** (what we did): the speed is not constant (limit speed is not reached yet) but the forces are small and the acceleration too.

- **Have a big viscosity:** the limit speed is quickly reached. The forces could be big, the friction is big enough to allow a small limit speed.

- **Have a very small r:** Gravitation and buoyancy forces depend on $r^3$ but the Stokes friction on r, so we reached the same conclusion as with a big viscosity.

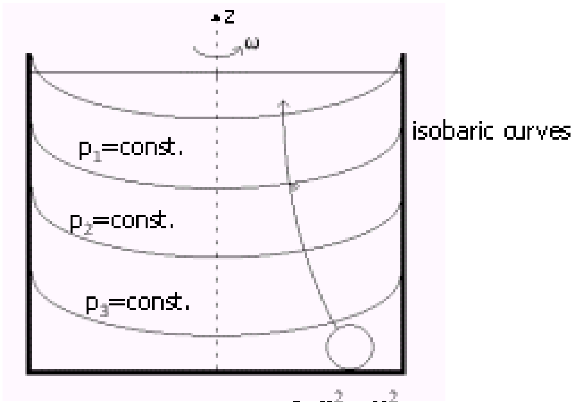
## Theory (with rotation):




$$F_{cp} = (\rho_{wat} - \rho_{ball}) \cdot V_{ball} \cdot r \cdot \omega^2$$

When the liquid is rotating the same forces act. There is, however, one new force acting which is the centripetal force. This force makes the ball moving towards the axis of rotation.

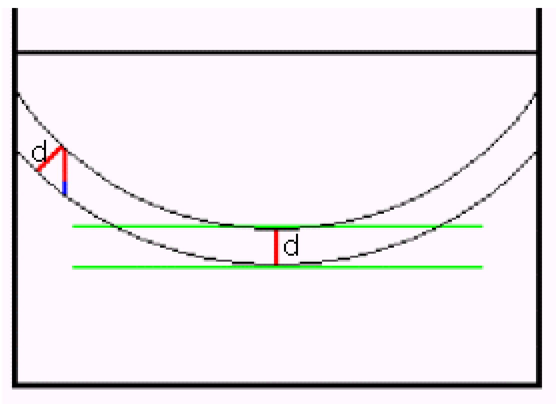
## Pressure distribution:

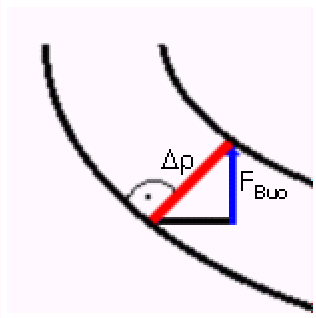



$$p = p_0 - \rho \cdot g \cdot z + \frac{\rho \cdot r^2 \cdot \omega^2}{2}$$

When the liquid is rotating the former plane isobarics become parabolic.

The mentioned parabolic isobarics are the explanation for the observed phenomenon that the ball is slower when the liquid is rotating.
We want to explain you our final solution.

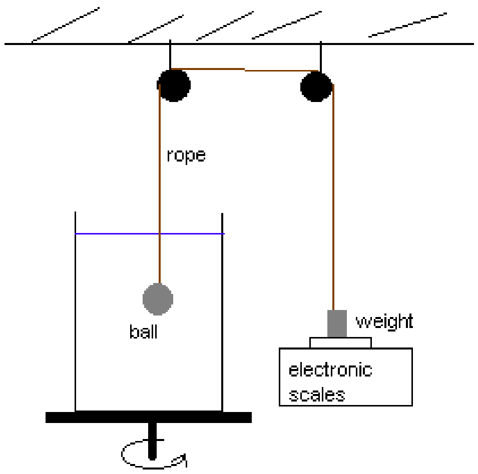



The red line in the centre represents the diameter d of the ball. The green lines symbolise the isobarics in the non-rotating liquid. In the non-rotating case we have a

pressure difference Δp on the height difference d which is the diameter of the ball. When the liquid is rotating and the isobarics become parabolic the vertical distance between the isobarics increases everywhere except in the axis of rotation.
So we have a pressure difference lower than Δp on the vertical distance d. With a lower pressure difference in vertical direction we get a lower buoyancy force in vertical direction which causes a lower upward speed.

In order to prove this theory we made the following experiment. We put a glass on a disk and put a ball on a rope inside. We led the rope across 2 rollers and fixed a weight on the other side which was standing on electronic scales. Then we started to rotate the disk with the glass on it. By increasing the angular velocity the weight shown by the electronic scales decreased, because the buoyancy force on the ball decreased, as predicted by our theory. So the ball "lifted" the weight on the scales.



sketch of the experimental setup

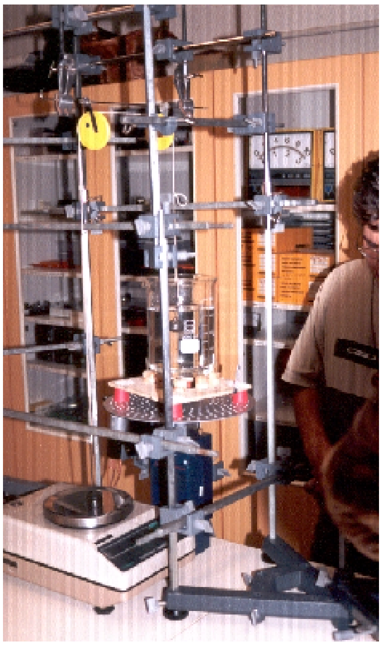


photo of the experimental setup

# Problem no.14 "Illumination"

The following assumptions were made:

- The bulbs are considered as point sources.
- The source emits the same energy in each direction (perfect radial wave).
- The light does not lose any energy on its way through the air.
- Both bulbs have exactly the same efficiency.

The problem is easy to solve, if the distance between the bulbs and the ball is very large . That means that the radius of the ball is small compared to the distance. In this case the intensity on both sides must be equal.

The intensity is proportional to the power of the source divided by the distance squared. If the intensity on both sides is equal, we have P1 divided by a1 squared is equal to P2 divided by a2 squared, where P1 and a1 are the power and the distance on one side and P2 and a2 on the other side. So the ratio between a1 and a2 is squareroot of P2 divided by P1. With P1=40W and P2=100W the ratio between the radii is approximately 0.63246.

$$I \sim \frac{P}{a^2}$$

$$\frac{P_1}{a_1^2} = \frac{P_2}{a_2^2}$$

$$\frac{a_1}{a_2} = \sqrt{\frac{P_2}{P_1}}$$

$$P_1 = 40\,W, \quad P_2 = 100\,W \quad \Rightarrow \quad \frac{a_1}{a_2} \approx 0{,}63246$$

If the ratio between the distance and the radius is small the problem is more complicate. The intensity varies at different positions on the ball. We think the two sides of the ball seem equally lit, if the power on both sides is equal.

On each imaginary sphere with the radius r and the centre in the light source, the energy that is radiated onto the sphere per second is equal to the energy emitted per second from the source.

A further step is to examine which part of the light radiated onto the sphere shines onto the ball as follows:

$$P_r = P_s \cdot \frac{A}{4 \cdot r^2 \cdot \pi}$$

$$A = 2 \cdot r \cdot \pi \cdot h$$

$$h = r - r \cdot \cos\varphi \;= r \cdot (1 - \cos\varphi)$$

$$\Rightarrow P_r = P_s \cdot \frac{2 \cdot r^2 \cdot \pi \cdot (1 - \cos\varphi)}{4 \cdot r^2 \cdot \pi} = P_s \cdot \frac{1 - \cos\varphi}{2}$$

In this formula Pr is the part of the light that shines onto the ball, Ps is the power of the source, A is the area of the big sphere that takes up the table tennis ball and r is the radius of the sphere.

$$\textit{furthermore}:$$

$$\varphi = \arcsin\frac{b}{a}$$

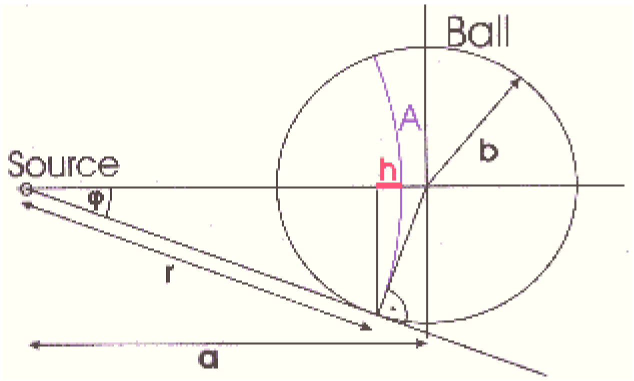
$$\Rightarrow P_r = P_s \frac{1 - \cos\left(\arcsin\frac{b}{a}\right)}{2}$$

$$\textit{to solve}:$$

$$P_{r\_left} = P_{r\_right}$$

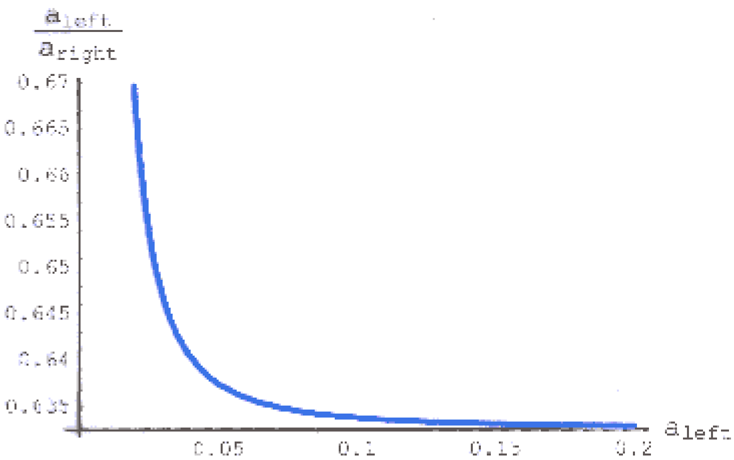
$$P_{s\_left} \frac{1 - \cos\left(\arcsin\frac{b}{a_{left}}\right)}{2} = P_{s\_right} \frac{1 - \cos\left(\arcsin\frac{b}{a_{right}}\right)}{2}$$

For this last equation “Mathematica” provided us with an exact solution.




sketch to explain the characters in the formulas above

So we plotted the ratio a_left/a_right versus a_left.
We can see, that if the distance between the bulb and the ball (a_left) goes to infinity the ratio is 0,63246. This is also the solution which we already knew from the assumption of large distances between bulbs and ball. So the result should be correct.




If we forget our assumption that the filament of the bulb is a point source, we can say that one infinitesimal small part of the power is:

$$d\,P_r = d\,P_s \frac{1-\cos\left(\arcsin\frac{b}{a}\right)}{2}$$

$$\Rightarrow P_r = \int d\,P_s \frac{1-\cos\left(\arcsin\frac{b}{a}\right)}{2}$$

However not even for simple shapes like lines or arcs this equation is solvable. It is only possible in a numerical way.