PHYSICS FAIR

NATUURKUNDE KERMIS

The Intuition Provoked

or

The Unexpected in Physics

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PHYSICS FAIR, The Intuition Provoked

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Presented is a collection of experiments that have some unexpected aspects. Purpose is to show people ('the man in the street') that physics can be great fun, that nature can behave unexpectedly and that human beings are able to manipulate nature in a surprising way by designing and performing experiments. I'm sure that not only the layman will be surprised by what he will be observing. Also many physicists will be puzzled or even deceived from time to time, not by the lack of knowledge, but by bearing a burden of too much knowledge.
This collection is started in the beginning of the eighties as a welcome fair for newly arrived students in physics at the University of Amsterdam. Many colleagues have brought in ideas of, sometimes well known, experiments. My task was to think, if possible, of new applications and new presentations. Later I have extended the collection to over 100 experiments.
The Physics Fair is held a few times per year for a general audience of thousands of people, hoping that people will gain a little affinity to physics (or science). Our wish would be fulfilled for the most part, if, at least, the public opinion would not reject it.
The Physics Fair has been active at many occasions and celebrations, as well in The Netherlands as abroad, to mention a few: as a returning item in a television series on a Dutch TV channel, World Expo in Seville (Spain), the 40th anniversary of CERN, Tyndall lectures in Ireland, Science Fairs in Poland, Physics on Stage in Geneva, Antwerp in Belgium, Goteborg in Sweden …..

This booklet doesn't cover all of the experiments in the collection, nor is it a technical description. It is meant to instruct my assisting students how they could present the experiments. If the explanation is denoted as 'Explanation 1', a simple explanation is given or the experiment is made plausible, hopefully understandable for the layman. For people more interested and trained in physics 'Explanation 2' is given.
If a simple explanation cannot be given without any knowledge of physics, the explanation will be denoted by 'Explanation 1, 2'.

The experiments of the Physics Fair may be demonstrated in market-style, with the help of many assistants (students), or a selection may be presented in a lecture or a series of lectures.

2. Ping-pong-ball (Bernoulli)

With an air blower one can blow away certain light objects, such as a ping-pong-ball lying on a table. This is easily demonstrated.
Now the jet of air is directed upwards, and the ball is placed above the nozzle in the jet stream. *Observe how in this case the ball is not blown away. On the contrary, the ball is captured by the jet of air.* The jet can even be given a considerable angle with the vertical, without losing the ball.

Explanation 1: Gravity is equal in strength to the force of the air that pushes the ball upwards.

Explanation 1, 2: The ball is pushed up by the jet of air. Further away from the nozzle this upward force gets weaker. When the ball reaches a certain height, this force will have equilibrium with gravity. That's why the ball stays in a stable position in the vertical direction. Sideways the ball is also positioned stable. A physical law states, that where air (gas or liquid) flows faster, the pressure will be lower (Bernoulli). As soon as the ball would move sideways, the stream of air doesn't surround the ball symmetrically anymore. The side of the ball closest to the center of the jet is surrounded by air of greater speed. As the pressure of the air is lower there than at the other side of the ball, the ball will be pushed back to its stable position.

3. Polarization (90º en 45º)

There are two sets of square cut sheets made of polarizing material. Both sets will darken in a similar way as one of the sheets is rotated over 90 degrees.
Now both sets are put in the transparent mode. *Observe how one set stays transparent and the other set gets dark under the same operation of flipping one sheet.*

Explanation 1, 2: Light may be regarded as a wave-like phenomenon. A polarizer selects a preferential direction of oscillation in such light waves. If the polarizers are parallel, the first polarizer selects a direction of oscillation and the second one lets this wave pass (transparent mode). The wave is blocked by the second polarizer (also called analyzer) when its preferential direction is perpendicular to the first polarization direction (dark mode).
The two sets of polarizing sheets are made of identical material. The only difference lies in the way the sheets are cut with respect to the polarization directions. One set is cut with the sides of the squares parallel to the polarization direction and in the other set the sides of the squares subtend angles of 45 degrees with the polarization direction.

5. Polarization (tools)

Two sheets of polarizing material are placed in such a way that no light can pass. Pieces of plastic and nicely cut pieces of cellophane are laid between the polarizing sheets. *Observe how colors appear*.
These colors also appear when transparent materials (glass or Perspex) are submitted to mechanical stress. One application can be found in designing tools. A Perspex model of a tool is placed between two perpendicular polarizing sheets. If forces are exerted on the tool, the spots with the greater tension or stress are easily recognized by coloring.

Explanation 1: See also 4. The pieces of plastic between the polarizers rotate the direction of polarization slightly, so the light waves incident on the second polarizer (also called analyzer) are no longer perpendicular to the polarization direction of the second sheet. Some light is coming through. A similar phenomenon is observed when one looks through polarizing sunglasses at the windshield of a car.

Explanation 2: See also 4. The pieces of plastic between the polarizers rotate the direction of polarization of the light slightly. The light waves incident on the second polarizer (also called analyzer) are no longer perpendicular to the polarization direction of the second sheet. The light can partially pass the second sheet. The extent of the rotation depends on the stress in the material, but it also depends on the wavelength (color) of the light. The colors are wildly varied in areas with great stress.

7. Falling upwards

Any falling object will spontaneously fall from a higher place to a lower place. So does the cylinder in the next experiment.
The cylinder is put on two nearly horizontal rails. The cylinder will be rolling along the rails seeking for the lowest part. This experiment shows the audience which side of the rail is the lowest.
Now a double-cone is put on the rail. One expects, of course, that this object will also fall to the lowest point. *Observe how this object spontaneously is falling upwards!*

Explanation 1, 2: Of course this object will not fall upwards. The rails do not run parallel. They are wider apart from each other at the higher end of the rails. The double-cone seeks for this higher end. By rolling towards the higher end, the object is, by its shape, sliding down between the rails, so that the center of mass finds a lower position.

8. Testing free fall

Two cylinder-shaped objects are externally nearly identical. Two tubes, one made of aluminum and the other made of Perspex, are positioned vertically. The experimenter drops the two objects (the experimenter should know which is which) at the same time through the tubes. By the sound the objects make when coming down on the table, one can hear that the objects hit the table at the same time. They fall with equal speed. Now the experiment is repeated. *Observe how one of the objects is delayed for almost one second.* The experimenter had interchanged the objects!
To the audience is explained that one of the objects is a strong magnet. Magnets do attract objects made of iron, but not aluminum! This is easily demonstrated.
Explanation in terms of 'eddy-currents' is given.
How do these eddy-currents flow? What is their direction or orientation? The circular shape of the crosssection of the tube suggests that the eddy-currents are directed along these circles, perpendicular to the longitudinal axis of the tube. To verify this, the magnet is dropped through an aluminum tube, which has a longitudinal cut, as to interrupt the currents. There appears to be no significant difference in delay between a closed and a cut tube! When the magnet falls through a ringed tube (Perspex with many aluminum rings) the delay is considerably less.

Explanation 2: Initially the non-magnet falls through the aluminum pipe and the magnet through the Perspex pipe, giving two identical free fall motions of the objects.
When the magnet is dropped through the aluminum pipe, eddy currents in the mantle of the pipe will delay the fall.
From the experiment it follows that the longitudinal cut does not interrupt the eddy currents, but the rings do. Conclusion must be that the eddy-currents circle in vertical planes.

9. Atmospheric pressure

Air seems to be virtually nothing: it cannot be seen; its density is very low; you can freely move your hands through it and hardly feel anything, etc. Yet, forces associated with air can be rather substantial.
A large glass tube, with two open ends, is placed with one end on a table, which is connected to a vacuum pump. A sheet of cellophane is laid over the upper end of the tube. The cellophane must firmly be held in position. Because of the suction, the cellophane sheet is curved downwards. All of a sudden the sheet is bursting with a deafening 'boom'.
Caution: this experiment may be unpleasant for people with sensitive ears or hearing aids.

Explanation 1, 2: Without suction, over and under the sheet there is the same atmospheric pressure. There is equilibrium. When the air is taken out of the tube there only remains the atmospheric pressure outside the tube and sheet. It is easily heard how strong the forces on the sheet were.

12. Fragile rubber

Liquid nitrogen has a temperature of −196 ºC. When materials are immersed in liquid nitrogen, they become extremely deep-frozen. The properties of these materials can be changed dramatically. At room temperature a rubber hose is flexible. It will not be damaged, if twisted, bent or otherwise maltreated (within reason). At the temperature of liquid nitrogen, rubber doesn't look like rubber anymore. *Observe how the hose can be broken like glass by the blow of a hammer, or by flinging it against the table.*

Explanation 1, 2: The structure of rubber is changed by the low temperature. The material is much harder; the atoms are tighter together. This makes the material also easier to break into pieces.

14. Liquid nitrogen & balloons (and He-balloon)

Liquid nitrogen has a temperature of −196 ºC. Liquid nitrogen is poured over an inflated balloon. *Observe that only a thin skin-like object is left over from the balloon.* When it is warmed up, the balloon regains its original volume and shape. A bit more spectacular effect is achieved with a helium filled balloon. At first the balloon tends fly up in the air, but it is held in position by a weight. When cooled by liquid nitrogen, the balloon shrinks (not as much as the air filled balloon) and it sinks down on the table. When heating up, the balloon slowly rises and flies up in the air again.

Explanation 1: The volume of the balloon decreases by the low temperature, because the gas inside is cooled down. At room temperature the helium balloon is lighter than air with the same volume of the air, which makes it go up. At low temperatures its volume is too small, so it is heavier than the same volume of air.

Explanation 2: In the balloon there is an isolated amount of air or helium. By the low temperature the pressure of the gas inside the balloon tends to decrease. The atmospheric pressure, however, forces the balloon to a smaller volume until the pressure inside and outside the balloon are equal (neglecting the surface tension of the skin of the balloon). At these temperatures air can be compressed more than helium, because it contains components than can be liquefied or frozen (nitrogen, oxygen, carbon dioxide, water). At these temperatures helium always will be a gas. When heated up, the pressure in the balloon rises, the balloon expands, and will reach to its original shape.
The helium filled balloon flies up in the air, because the average density of the balloon and helium together is lower than the density of air. Just like a piece of wood, held under water, tends to rise to the surface of the water. When the balloon is cooled, the volume of the balloon is greater, resulting in a greater average density of the balloon and helium. This makes the balloon come down.

15. Heavy fog (liquid nitrogen & hot water)

Liquid nitrogen has a temperature of −196 ºC. Some liquid nitrogen is poured in a tray containing hot water. *Observe the thick fog that is created.*

Explanation 1: The water vapor condenses to little droplets by the cold nitrogen, which we see as mist.

Explanation 1, 2: The hot water is producing much water vapor. Liquid nitrogen is at −196 ºC at its boiling point. When the nitrogen comes in contact with the water, it will boil heavier, producing nitrogen vapor (gas) at a fast rate. The evaporated nitrogen has, however, still a very low temperature. By this evaporated nitrogen, the water vapor condenses to small water drops, which we see as mist.

16. Ping-pong ball & liquid nitrogen

A table-tennis ball is immersed in liquid nitrogen (−196 ºC). The nitrogen starts to boil more rapidly than it already did. After a while the fluid comes to rest again and it just boils gently as before the immersion.
Ask the audience what will happen and why, when the ball is placed on the table. (Don't tell yet that the ball is slightly prepared; this is the only experiment with a hidden trick!).
With forceps the ball is taken out of the nitrogen and placed on the table. Almost immediately the ball begins to spin, initially slowly and later amazingly fast. To see the effect of spinning, the ball is decorated with colorful stripes. The stripes will vanish and the surface of the ball will seem whitish.

Explanation 1:
Liquid nitrogen was sucked into the ball. Placed on the table, the nitrogen heats up and the vapor (gas) leaves the ball through a pinhole with high speed.

Explanation 2:
Nearly invisible there is made a pinhole in the surface of the ball. At first air (at room-temperature) fills the inner side of the ball. Immersed in the liquid nitrogen, the air inside the ball cools down and the pressure of the air is lowering. Through the pinhole liquid nitrogen is sucked into the ball. (The liquid is boiling fiercely now because of the heat that is given off by the ball). As soon as the ball reaches the same temperature as the liquid, the fluid boils gently again.
When the ball is put on the table, heat from the surroundings is absorbed. The liquid nitrogen in the ball starts to boil more fiercely. Vapors and gasses can only escape through the pinhole (drilled not perpendicular to the surface of the ball). This acts as a jet engine and makes the ball spin.
If the right types of colors red, green and blue were used, the human eye would interpret a mixture of these colors as white.

18. Hovering and jumping ring

An aluminum ring is placed over an iron core of a coil. The coil is connected to a variable transformer (variac). The voltage is increased from zero to a certain value. *Observe how the ring is hovering around the core.*
Now the coil will be directly connected with the mains. The power is switched on. *Observe how the ring jumps and reaches a height of about 1 meter.*
This experiment is known as 'The Thompson ring'.
Cooling the ring to the temperature of liquid nitrogen (−196 ºC) can dramatically increase the height of this jump. *The ring may easily jump to a height well over 6 meters!*

Explanation 1: The coil, the ring and the core act as a transformer. The ring can be considered as the secondary coil. The induced current in the ring produces a magnetic field in such a way that the ring is repelled. A stronger magnetic field is produced when the ring is cooled, so it will jump to a greater height.

Explanation 2: The coil, the ring and the core act as a transformer. The ring can be considered as the secondary coil. As the voltage rises, the induced current in the coil will increase. This current is oriented in such a way, that the magnetic field produced by this current, is opposite to the field produced by the primary coil. This causes the ring to be repelled. At a certain current there is equilibrium between this repelling force and gravity: the ring is hovering.
When 220 V is switched on, suddenly there will be a strong current in the ring. The repelling force is large and the ring will jump up high.
At low temperatures metals will have low electric resistance. Electric currents can reach higher values, thus the repelling forces will be stronger.

19. Donald Duck

Helium is a noble gas, meaning that it is chemically inert (it doesn't get involved in chemical reactions). A balloon is filled with helium. *Ask a person in the audience to inhale the helium and ask this person to speak.* This persons voice sounds much like that of Donald Duck.
The person must be convinced that inhalation of helium is harmless. The only thing that happens is that he misses one breathing cycle, as no oxygen is inhaled. (Deep sea divers and, formerly, some astronauts work and live in a helium-oxygen atmosphere).
First the person must breathe out completely, (as little air as possible left over in the lungs), and then he must inhale the helium (without inhaling air through the nose).
Avoid laughing, because one loses the helium too quickly out of the lungs and no effect will be heard.
When the person can't find words to say, let him read something out loud (preferably in his own language).
The effect is best heard on a male voice.

Explanation 1: The sound of your voice is determined by vibration of the air in your mouth and throat cavities. The vibrations are changed when the air is replaced by helium.

Explanation 2: Whilst speaking, your vocal chords oscillate and produce more ore less square sound waves. These waves are composed of many frequencies. Your throat cavity and your mouth cavity select by standing wave principle two frequencies (called formants) that are characteristic for your speech. The velocity of sound in helium is greater than in air. This means that standing waves are formed at higher frequencies.

21. Water and sand

A plastic wash bottle is filled with water and sand. The water level can be read from the tube of the spout. *Ask the audience what will happen to the water level, when the bottle is squeezed. Will the level rise, fall or will it stay the same?*
If you would like to bet on it, you could always win! You can change the level as you like, or even not change it at all.
If you squeeze the bottle at the top, the level will rise. Squeezing at the bottom of the bottle will cause the level to fall. Somewhere in the middle of the bottle, a point can be found where squeezing doesn't change the water level at all.

Explanation 1: Pressing at the top of the bottle, makes the volume of the bottle decrease and the water level rise. This is the usual behavior of such a bottle. Squeezing at lower part of the bottle will press out the bottom. This makes the volume of the bottle greater. The water level will fall. Somewhere in between, both effects will compensate each other and no change of the water level is observed.

Explanation 2: The sand works like a sort of buffer or blockade, so the bottle can only be deformed on the spot you are squeezing. When you squeeze the top of the bottle, the volume of the bottle is decreased and the water level must rise, since the total volume of the water and sand is constant. This is the usual behavior of such a bottle.
Why is the volume of the squeezed bottle smaller?
Consider the bottle as a cylinder. The wall of the cylinder has a certain area. One of the properties of a cylinder is the following (circles and spheres have similar properties): at a given area of the wall, the volume of a true cylinder is greater than the volume of any similar object with a non-circular crosssection. The squeezed bottle is not cylindrical anymore, so its volume is smaller.
Squeezing near the bottom of the bottle will press out the bottom a little. The sand buffer prevents the bottle to be deformed somewhere else. The result of the pressed out bottom is that the volume of the bottle increases, so the water level drops.
Why is the volume of the bottle with a pressed-out bottom greater?
Of all the objects with a given area of its surface, a sphere has the largest volume.
When squeezed at the bottom, the lower part of the bottle will have a more sphere-like shape. That is why the volume increases and the water level goes down.
Somewhere between the bottom and the top a point can be found where both effects compensate each other. In this case the volume of the bottle stays constant as well as the water level.

22. Lamps lighting up in your hand

A Tesla-transformer produces a very high voltage, more than 100.000 V. *Ask a person in the audience to take hold of a metal rod. Let the person approach one of the spheres of the Tesla-transformer with the rod pointing towards the sphere. Observe how sparks jump between the sphere and the rod, while the person doesn't seem to feel anything! Emphasize that the high-voltage is well over 100.000 V and that the person him- or herself is the conductor for the current!*
Now replace the rod by a fluorescent-tube. *Observe how periodically the tube flashes in the hand, without any leads or whatsoever!* Again the person acts as a lead.

Explanation 1,2:
The Tesla-transformer is powered by a 24.000 V DC power supply. This supply is connected to a capacitor and a coil (primary) that are wired in parallel. In the lead of the coil there is an air gap. As soon as the tension over the gap is sufficient high, a spark jumps over. This short term current causes an oscillation in the capacitor and the primary coil. The secondary coil, with much more turns than the primary coil, produces a high voltage by electromagnetic induction.
For a spark of 1 cm length in dry air a tension of about 20.000 V is needed. With this apparatus sparks with a length of 6 or 7 cm (or even longer) are easily made, so the tension reaches up to 120.000 or 140.000 V (or even more).
In the gas with which the fluorescent tube is filled, there are always small amounts of charges present. By these high tensions the charges in the tube are accelerated, causing the gas molecules to produce light.
The frequency of the electric oscillations in the primary and secondary coils of the transformer is very high, about 500 kHz to 1 MHz. At these high frequencies, electric currents do not activate the nerves and muscles in the body. Because of the low power the currents don't dissipate much energy (heat) in the body. That is why one doesn't feel the current; the only thing one may feel is the spark impinging on the skin and nothing more.

23. I Love You

A piece of wire is artistically bent in the shape of the characters 'I ♥ U'. The wire will be deformed by the experimenter. The wire is more or less stretched out or bent on other places.
Caution: don't make the wire too sharply curved, as it will become totally unusable.
After deformation, the wire is placed in a tray containing warm water.
Observe how the wire, almost immediately after touching the water, returns to its former shape.

Explanation 1:
The wire is made of a type of material that is also known as 'material with memory'.
When manufactured, the wire was, so to speak, baked in the shape of 'I ♥ U'. At room temperature the material can be deformed, but after heating it 'remembers' its original shape.

Explanation 2:
The wire is made of a special alloy, named Nitinol, consisting of nickel and titanium.
This type of alloy is also known as 'material with memory': one of its properties is, that is seems to remember its original shape after deformation. The manufacturer had given the wire a special thermal and mechanical treatment. At a certain temperature the wire has been given a certain shape, in this case the shape of the characters 'I ♥ U'.
At room temperature the wire can be deformed from the given shape. At a sufficient high temperature (in this case about 50 to 60 ºC) the wire tends to return to its original shape.
The secret of this 'shape memory' lies in reversible phase transitions in the wire, from one crystalline structure to another. At these transitions mechanical and thermal energy are interchanged.

24. Thermobile

An endless metal wire is wound over two pulleys. One pulley is dipped into warm water and the other is sticking up in the air. By hand one of the pulleys is made to rotate a little.
Observe how the pulleys and the wire are rotating continuously.
If the lower pulley is taken out of the water, the rotation will stop. The motion can be restarted by dipping the pulley into the water again.

Explanation 1, 2:
The wire is made of a special alloy, named NiTiNOL, consisting of nickel and titanium.
This type of alloy is also known as 'material with memory': one of its properties is, that it seems to remember its original shape after deformation. The manufacturer had given the wire a special thermal and mechanical treatment. At a certain temperature the wire has been given a certain shape, in this case the shape of a straight line.
At room temperature the wire is deformed from shape of the straight line, as it follows the contours of the pulleys. At a sufficient high temperature (in this case about 50 to 60 ºC) the wire tends to return to its original shape, exerting a force on the bottom pulley. If the pulley would not be spinning, this force would be symmetrical and no motion would be observed. In the case the pulley is already spinning, the part of the wire which suddenly is heated by the water will immediately tend to stretch, while the part of the wire which is leaving the water will gradually cool off and become slowly deformed. The wire exerts a resultant force on the pulley, which causes the whole constellation to rotate.
The secret of this 'shape memory' lies in reversible phase transitions in the wire, from one crystalline structure to another. At these transitions mechanical and thermal energy are interchanged.
The kinetic energy needed for the motion of the wire and of the pulleys, is supplied by the heat of the water. Normally this kind of heat is regarded as non-usable energy; it is merely dissipated to the surroundings. In this type of experiment the heat of the (relatively low temperature) water is converted to (maybe) usable kinetic energy.

25. Cartesian diver

An object in the shape of a small test-tube is just floating upside-down in water in a bottle. The bottle is completely filled with water. The thumb is placed over the opening of the bottle. *Observe how, with no visible effort, the object (diver) can be positioned at any depth in the water.* It can go down, it can go up and it even can be at rest anywhere you like in the bottle. *Invite the audience to try it themselves.*

Explanation 1, 2: In the tube (diver) there is a small bubble of air. When the thumb is pushed on the water, the air in the bubble will be compressed. It takes less space and the tube is filled with more water. This makes the tube heavier and makes it sink. By regulating the pressure of the thumb, the diver can be manipulated.
Because water is not easily compressed, the effect of the thumb will only be on the air bubble. Since the volume of the bubble is small, these movements of the thumb need only be small.

26. Tornado

The openings of two bottles are connected with each other. One of the bottles is filled with water and the other is empty. When the empty bottle is held down, water from the upper bottle is dripping slowly in the lower bottle.
Now the upper bottle is rotated a few times around a vertical axis. *Observe how fast the water runs in the empty bottle.*

Explanation 1: By rotating an analogon of a tornado is formed. Air from the lower can escape through the 'eye' of the tornado.

Explanation 2: When the full bottle is just placed upon the empty one, the water is only dripping: when the water comes down in the lower bottle, air is pushed away by this water and it cannot easily pass the water column above in the upper bottle (depending on the diameter of the opening between the two bottles). When the upper bottle is rotated a few times, The fluid starts to rotate and forms a sort of tornado. The 'eye' of the tornado forms a sort of tunnel through which the air can flow from the lower bottle to the upper bottle, as the water comes down fast. The rotation must start by some unbalance (external forces) and it is swept to higher speed, in this case, by the energy that is released when the water moves to a lower place, where it has lower gravitational energy.

27. Magic stick

A stick (homogeneous aluminum rod) has a length of about 1,5 m. Let the stick rest on two fingers, so that the fingers are symmetrically near the ends of the stick. *Ask the audience what will happen, when the fingers are slowly brought together (will the stick fall or not, where do the fingers meet?).* The stick will not fall off the fingers. The point where the fingers meet is the point that divides the stick into two equal parts (halves). *Present the explanation in a way like given below, to increase the suspense for the next experiments. Avoid at this point the term 'center of mass'.*
Now the stick is laid asymmetrically on the fingers. The above experiment is repeated. *Ask the same question to the audience.* The result is the same: the stick will not fall and in this way the middle of the stick is found. The explanation (see below) using the term 'friction' is given.
Now friction is influenced by using one bare finger and one finger in a glove (or a piece of rubber as a finger). The same questions are asked and the same experiment is done. Hopefully one is astonished that the results remain the same, even under these circumstances.
As a last experiment the stick is made inhomogeneous by hanging a weight on one end of the stick. Ask the same questions and perform the same experiment. The result is that the stick still won't fall off the fingers but the place where the fingers meet is different this time.

Explanation 1, 2: Initially the stick exerts the same force on both fingers. When the fingers are moved, the force on one of the fingers will be greater than on the other. The finger closest to the middle of the stick will have the greater force and thus the greater friction. The other finger can slide towards the middle of the stick until the force on this finger is greater. Now the friction at the first finger is less, so this finger can move towards the middle, etc, until the fingers meet under the middle of the stick.
This is independent of the starting point of the fingers and also independent of the type of friction.
Instead of 'middle' of the stick, one should speak about 'center of mass' of the stick. At a homogeneous stick these points coincide.
At the inhomogeneous stick the fingers also meet at this 'center of mass', but its position is not at the middle of the stick.

28. Light and water

A laser is switched on. *Ask the audience if they can see the laser beam.* They cannot, unless smoke from a cigarette, or dust or water mist is blown in the region of the beam. *Observe how perfectly straight the light beam runs over a considerable distance.* Even if the light beam is disturbed, for instance by a grating, after the disturbance the light beam(s) remain straight.
Now the light beam is directed through the outlet pipe of a transparent 'overflow vessel'. Still it remains straight. Water is now poured into the vessel and water runs out of the outlet pipe. Observe how the light beam is captured by the water and how it is curved along the jet of water.

Explanation 1, 2: One cannot see a light beam that passes without hitting the eye. Such a beam can be seen if some scattering objects (smoke particles, dust particles, drops of water) are brought into the beam. Some light is scattered towards the eye and one can see the light beam.
Light always travels along a straight line, even in the water jet. If one observes closely, one can see that inside the water the light is reflected many times against the surface of the water jet. Between the reflections the light follows a straight line. The light cannot escape from the jet because of 'total reflection' which occurs when light travels, at a large angle of incidence, from a medium of higher optical density (water) to a medium of lower optical density (air).
This principle is used in optical fibers.

29. Disgusting

A marsh-mellow (covered with chocolate) is put in a vacuum chamber. It looks delicious. Then the suction is switched on. *Observe the revolting growth in size of the marsh-mellow.* When the air is admitted into the chamber, the size of the marsh-mellow decreases and with a little luck it will regain more or less its original shape. Anyhow, it still is just as tasteful as before.

Explanation 1, 2: The marsh-mellow consists of many air bubbles. When the pressure of the surrounding air is diminished, the bubbles will expand, because of the greater pressure of the air inside the bubbles. If the bubbles do not break open, this process is reversible, so the bubbles will have their original volume when exposed to atmospheric pressure again.

30. Inflating by sucking

A balloon is not inflated and is sealed with a knot. Let the audience, for the time being, believe what they see: an empty balloon. This balloon is placed in a vacuum chamber and the suction is switched on. *Observe that the balloon increases in volume as the pressure of the air in the chamber is decreasing.* When the air is brought back to atmospheric pressure, the balloon has its original size again.

Explanation 1, 2: Although the balloon is not inflated, it contains, however, somewhat air anyhow. When the pressure of the surrounding air is diminished, the balloon will expand, because of the greater pressure of the air inside the balloon than outside the balloon.

31. Solution of the energy problem

Energy cannot be gained or created 'out of nothing'. In the future there will be an energy crisis. There will be a shortage of energy of the right type: mechanical energy. Here an experiment is presented that may solve this energy problem.
A few magnets are placed on a rail. The distance between the magnets is about 5 to 10 cm. Two (or three) small steel balls are placed against each magnet, at the same side of the magnets. Another steel ball is given a very small push towards the other side of the first magnet, so this ball has very little kinetic energy. With low speed it will gently roll towards the first magnet. It will bump against this magnet. *Observe how the last steel ball at the other side of the magnet leaves the magnet with larger speed. This ball hits the next magnet, etc. As the result of an accumulating reaction the last ball has considerable speed.* The kinetic energy invested in the first ball yields a larger kinetic energy in the last ball. The effect of gaining energy is more convincingly seen by inclining the rail upwards. Again the first ball is given a small push and the last ball has enough energy to climb up to the end of the rail. At the end it falls off the rail.
Is energy really created in this experiment?

Explanation 1: The answer is 'no'. The energy is not only invested by the small push of the first ball, but also by the hand while the experiment is set up.
Steel balls are attracted to magnets. The rolling ball gets attracted by the magnet and gains speed. This speed is transferred to the last ball at the other side. The last ball at each magnet is bound more loosely to the magnet than the first one, which lies directly against the magnet. That's why this ball comes off so easily.

Explanation 2: The answer is 'no'. The energy is not only invested by the small push of the first ball, but also by the hand while the experiment is set up.
Steel balls are attracted to magnets. When the ball is given a small push, it rolls towards the magnet and it gets captured in the attraction sphere of the magnet. The ball gains kinetic energy at the cost of potential (magnetic) energy, according the laws of physics. When it collides with the magnet, momentum and kinetic energy is transferred to the last ball at the other side of the magnet. This ball is bound more loosely to the magnet than the incoming ball gets bound. This means that only a part of the transferred kinetic energy is lost to set the ball free from the magnet. More kinetic energy is left for this ball. This ball moves towards the second magnet, etc.
When the experiment is repeated, the balls must be pulled off the next magnet and brought back to the former. This costs energy and this energy is brought in by the hand. This amount of energy is equal to the energy that seems to be gained.
Alas! Again just another type of conversion of energy, instead of creation!

32. Smooth landing

This very simple experiment can be performed at home. The apparatus consists of a matchbox with matches and a hard horizontal surface (for instance a kitchen table).
Hold the matchbox about 20 cm above the table in a vertical position. *Ask a person in the audience if he or she is able to drop the box so that it lands on its side without tumbling over.*
In general the audience will fail. The effort will be successful if the box is half filled with matches. The box should be opened halfway, the open end at the top. When released, the box will land and stay in the same upright position. *Demonstrate this trick that does it!*

Explanation 1: When the box is closed, the box will bounce back on the table surface, causing the box to rotate a little. By this rotation the box will tumble as it reaches the table again. By sliding the box a little up, you will have the same effect as bending your knees while landing after a jump. It prevents the box from bouncing back.

Explanation 2: When the box is closed, the box will bounce back on the table surface. During the release, the box may gain a little rotation by frictional forces. This and the bouncing process on the table causes the box not to bounce up exactly vertically. Due to this rotation the box will tumble over. While bouncing, kinetic energy is more or less conserved, so the box keeps velocity after the collision with the table. When the box is opened halfway, the box will close while landing. Frictional forces convert the initial kinetic energy to heat, leaving no kinetic energy after the collision. (One may say the shock is absorbed).
In daily life we are often confronted with this problem of landing. Landing after a jump with stretched legs, mostly causes an imperfect landing. By instinct we know already the solution: bending our knees will absorb the initial kinetic energy.

33. Celtic stones

A stone (made of wood or metal) has the shape of an ellipsoid cut in half along the long axis. Give the tip of the stone a little push down with your finger. *Observe how the stone is always rotating in the same direction.* There is a right-handed and a left-handed stone, that always rotate in opposite directions. Try to force a rotation the other way round. This rotation is not stable and will soon stop. With the energy that is left over, the favourable rotation commences.

Explanation 2: Rotation is only stable round an axis with maximal (or minimal) moment of inertia. In homogeneous and symmetrical bodies, such an axis is coinciding with an axis of symmetry. In these 'stones' both axes (of symmetry and moment of inertia) do not coincide. Inside there are hidden weights.

34. Tippy-Top

A special shaped (mushroom-shaped) top is placed on a table with its 'head' down and 'leg' up in the air. In this position it is brought into spinning.
Observe that after a while the top 'stands up' by its own and continues to spin on its 'leg'.

Explanation 1, 2: Essential is the shape of the top. The shape of the head is such that there is no sharp point on top of it. It has a rather smooth, almost spherical surface. The top will soon show precession. After a while, the contact point of the top with the table is no longer coinciding with the rotation axis. It moves to other points of the top's head. Due to frictional forces and precession the top seeks for a more stable position.

35. Water rocket

A rocket is partially filled with water. The air above the water surface inside the rocket is brought under pressure by means of a bicycle pump.
The rocket is launched by opening a valve at the rear of the rocket and it will reach a height of several tens of meters.
When coming down, the rocket may cause some inconvenience or injuries to the audience. That's why the rocket is guided along a rope that is attached to a building, or tree.

Explanation 1:
In upright position and with opened valve, the compressed air will push the water out of the outlet of the rocket. This will push the rocket in the opposite direction.

Explanation 2:
A certain mass of water leaves the rocket with a certain speed (momentum).
The law of conservation of momentum dictates that the rocket and water (and the compressed air) as a whole, will have the same momentum before the launch as thereafter. So the rocket will get the opposite momentum. This will exert a force on the rocket through which it will be accelerated until there is no water (or compressed air) left. Thereafter the rocket will be subjected to a free fall (including friction). It will reach its highest point and then it will come down.

36. Grandfather's cigar

Three candles are placed on a table. The distance between the candles is about 20 cm. The table with the candles is put away from us at a distance of about 5 meters. The candles are lit. *Observe how it is possible, over a distance of 5 meters or more, to blow out just one of the candles, while the others remain lit.* The choice which one of candles will be blown out is arbitrary.
The candles are blown out by means of a smoke chamber. This chamber has a membrane-like backside (rubber sheet or cotton cloth). In the front of the chamber is a hole with a diameter of about 10 cm. By aiming correctly and by hitting the membrane with the palm of the hand, smoke rings will appear and the chosen candle will be blown out.

Explanation 1, 2: In the chamber smoke is produced by igniting special 'smoke pills'. By hitting the membrane, the air in the chamber will be compressed. The air will escape through the hole. In this type of unsteady convection (motion of gas), turbulences appear as smoke rings. These smoke rings propagate through the air with considerable speed as fairly stable configurations. When a candle is hit by a smoke ring, the flame is extinguished by the cooling effect of the turbulent air. The smoke has little or no effect in the process of extinction of the candle. The smoke is merely used to make the turbulent rings visible.

37. Heavy metal

Liquid nitrogen has a temperature of –196 ºC. When materials are immersed in liquid nitrogen, they become extremely deep-frozen. The properties of these materials can be changed dramatically.
A cowbell is made of lead. At room temperature the bell hardly sounds. The bell is brought to the temperature of liquid nitrogen. *Observe how the bell sounds somewhat clearer.*

Explanation 1, 2: The structure of lead is changed by the low temperature. The material is much harder; the atoms are tighter together. Sound production and propagation is more efficient with less energy loss.

38. The Pulfrich-effect

Two tennis balls are suspended from strings and pendulate out of phase in a vertical plane. Of a sunglass, one of the glasses is taken out. Look with one eye directly and with the other eye through the dark glass to the swinging tennis-balls. *Observe, how the balls seem to circle around each other.*

Explanation 1, 2: This illusion is caused by the different perception of light by the (human) visual system when the intensities of light are different.
Perception through the darkened eye is slightly slower than through the normal eye. Both eyes see the same objects. But when the objects move, both eyes see the objects in different positions, which gives rise to a sort of three dimensional impression.

39. Floating and sinking and hovering

The bottoms of two curved glass tubes are placed against one another, in such a way that the shape of the character 'U' is formed. One tube is filled with water and the other one contains air. In both tubes there is a small ball made of cork and the tubes are sealed. Our daily experience is confirmed: in the tube filled with air, the ball lies on the bottom and in the tube filled with water, the ball is floating. Now this U-shaped constellation is rotated around a vertical axis. *Observe how the balls change positions: in the water tube the ball sinks to the bottom and in the air tube the ball reaches the top.*

Explanation 1: Comparable with a centrifuge, the ball in the air tube will be flung out. The water will also be flung out, pushing out the lighter ball.

Explanation 2: If the ball in the air tube is forced to rotate as well, there must be a centripetal force acting on it. By this rotation the ball climbs up and comes to rest at a certain point. At this point the slope of the tube is such that a component of the gravitational force on the ball is equal to the centripetal force, needed for the rotation. Now the ball is hovering in the tube. As the rotational speed increases, the ball seeks for a steeper slope and will eventually reach the top of the tube. The same explanation holds for the water: the water will climb up. Because of the greater density of the water, it pushes lighter objects (ball, air bubbles) aside.

40. Double mirror, Triple mirror

Two mirrors are perpendicularly placed against one another. *Ask a person in the audience to look in the mirrors.* The image he sees is familiar to him, but not quite the same as the image at home. *Ask this person to touch his left ear.* Left and right seem to be interchanged! In these mirrors you can see yourself the way other people see you!
Tree mirrors perpendicular to each other form a corner cube. Observe the reflections that arise in this case, with respect to seeing a mirror image or not.

Explanation 1, 2: In a single mirror there is a single image. With these double mirrors you see the image of one mirror as an image in the other mirror, and the other way around. The two doubly formed images coincide. Because of the double reflection, the first mirrored image is mirrored again, resulting in the unexpected view on yourself.

41. Circular polarized light

A circular polarizer is a transparent filter. One can see right through it. When one places the filter between the hand and the eye, one can see the hand.
The polarizer is placed about 10 cm from a mirror. *Ask a person in the audience to look at an angle through the filter at the image of an object in the mirror.* The object must be located beside the filter (at the other side of the filter than the eye). Use for instance a finger as the object. The image of this object can bee seen through the filter.
Now ask the person to look at the image of his own face in the mirror. This vampire doesn't have an image! The image cannot be seen!

Explanation 1, 2: There are two kinds of circular polarizers: so called left-handed and right-handed polarizers. Light that passes a left-handed polarizer will be left-handed polarized. For the eye this light appears to be normal light. This light, however, will be blocked by a right-handed polarizer, and the other way around.
When you try to see your image in the mirror, the light must travel along the following path. First the light is emitted (reflected) from your face towards the filter. The light will pass the filter and gets circularly polarized. Then the light is reflected by the mirror. At reflection the orientation of the circular polarization is reversed. The light travels back to the filter and meets the filter again, but now with opposite orientation. The light is blocked and no light hits the eye.

42. Three Polarizers

A (linear) polarizer is a transparent filter. When two of such filters are placed behind each other, and when one of the filters is rotated, alternately one can see through them and one cannot. (Light can pass both filters or light is blocked).
The polarizers are positioned in such a way that the light is blocked. No light can get through. A third polarizer is shifted in between the two. *Observe how the light can pass the three filters, although it cannot pass the two filters.*

Explanation 1, 2: Light may be regarded as a wave-like phenomenon. A polarizer selects a preferential direction of oscillation in such light waves. If the polarizers are parallel, the first polarizer selects a direction of oscillation and the second one lets this wave pass (transparent mode). The wave is blocked by the second polarizer (also called analyzer) when its preferential direction is perpendicular to the first polarization direction (dark mode).
The third polarizer in between lets the light pass with a direction of oscillation which is a component of the direction selected by the first polarizer. This component is not perpendicular to the analyzer, so the light can (partially) pass.

43. Tesla discharge ball

In a tesla-ball (or lightning-ball) electric discharges are produced. *Ask a person in the audience to touch the glass ball.* The paths where the discharges take place are influenced by touching the ball.
Ask a person in the audience to take hold of a lighting-tube. The tube will be ignited in his hand.

Explanation 1, 2: A Tesla-ball is a transparent ball made of glass and it has been filled with a special gas. Inside there is another small ball that is electrically charged at a very high frequency. Between the inner ball and the outer surface of the large ball electric discharges take place. In this special gas these discharges cause a plasma which is visible as a sort of lightning. By grounding the ball with your hand, the discharge will preferentially take place at the location of your hand. You will not feel anything of this discharge, because of the high frequency: because of the high frequency the muscular cells are not activated and because of the small power the heat dissipation is not substantial.
A lighting-tube contains a similar gas as the tesla-ball. When the tube is kept in the near vicinity of the ball, discharges take place in the tube, so no wires are needed.

44. Communicating vessels (Bernoulli)

A few transparent tubes are partially stuck into a water basin (the water is colored by strawberry syrup). The water level in each of the tubes is equal. This is what one would expect. Now air is blown over the upper end of the tubes. The air is led through a cone shaped pipe, which is connected with the tubes. *Observe how the water levels in the tubes become different.*

Explanation 1: The air is flowing fast in the narrow region of the pipe. There the water level in the tubes is high, meaning that the pressure of the air is low. From this experiment we can learn that the pressure of a gas is low where the speed of the gas is high.

Explanation 2: The law of the 'communicating vessels' dictates that de water level in each tube should be the same, as initially is the case. An important condition for the validity of this law is, that the pressure (of the air) on all water surfaces must the same. When the air is blown, the conclusion must be that the pressure of the air in the tubes is not equal. Where the pipe is narrowest, the water level is highest, meaning that the pressure of the air is lowest. In this area of the pipe the air is flowing fastest. This principle has found many applications, for instance, the wing of an airplane (providing the lift through pressure differences over and under the wing) and the carburetor of an engine.

45. Discharge arc

A transformer produces a high voltage of about 4000 V. Two metal rods are placed vertically close to each other, with a small gap of air in between. The rods are connected with the transformer. As air is an electrical insulator, no electric current is flowing. Now the air between the rods is heated with the flame of a candle or match. *Observe how hot air is able to conduct electricity.* An arc of light that climbs up along the rods can be seen.

Caution: High voltage of low frequency (50 Hz) is used and the power that can be dissipated is considerable. Never touch the rods, when the transformer is switched on! Never leave the experiment unattended with power switched on! A Perspex screen must always be placed between the experiment and the audience. Especially beware of children, as they can make unexpected moves!

Explanation 1, 2: Air at room temperature is not conducting, because there are almost no free electric charges present. When air is heated, the velocities of the particles of the air are increased. Collisions between the particles are more fiercely. At these collisions charges can be freed from the particles (the molecules in the air get ionized). The charged particles will move from one rod to the other, which we call an electric discharge current in the air. Because of the high voltage, the charged particles are accelerated to such velocities, that through collisions light is produced.

46. Human reaction times

A Geiger-Müller-tube is meant to detect ionizing (radioactive) radiation. It is also able to detect components of cosmic rays, which are present always and almost everywhere. The tube is connected to appropriate electronics and produces electric pulses when detections take place.
This system is used as a random generator (a device to produce unpredictable results, in this case to produce electric pulses at unexpected moments). A pulse from this detection system starts a clock. At the same time a light is switched or a sound is produced in headphones. By hitting the 'stop' button, the clock will stop and one can read his/her reaction time. So one can react to a light (visual stimulus) or to a sound (auditive stimulus). In a suggestive way one can explain some things about light and sound. One could mention for instance the difference in propagation speed.
Ask the audience which of the two reactions will be faster. Let a person of the audience measure these reaction times.
In contrast with what one might think, the reaction to light signals is slower than to sound signals. (Typical reaction times are respectively 180 ms and 160 ms).

Explanation 1, 2: The eye-brain-system processes signals slower than the ear-brain-system.

47. Rayleigh disk

A disk, made of a thin copper foil, is suspended from a very thin nylon thread in front of a loudspeaker. This loudspeaker will produce a (rather low frequency) tone.
The cone of the loudspeaker is moving to and fro (oscillating) and in the same way the air is brought into oscillation by the loudspeaker. This motion is passed on to neighboring particles of the air. In this way a sound wave is created. (The sound waves travel through the air and may reach the ear: one can hear the sound). Being so close to the loudspeaker, the sound waves will certainly reach the small disk. Initially the disk is hanging on the string in an arbitrary position.
Ask the audience what will happen to the disk when the sound is switched on. Will it fly like a flag, will it rotate and come to rest in a certain (which?) position, will it keep rotating, or will it oscillate, ...?
The sound is switched on and the disk starts to rotate and comes to rest with its face perpendicular to the direction of the propagation of the sound. (The disk is parallel to the loudspeaker).

Explanation 1, 2: The oscillations are too fast to move the foil to and fro in an observable way. Because the air is in motion, the air will push against the disk. When the orientation is not perpendicular, one side will experience a larger force, than the other, resulting in a rotation (momentum) until the forces cancel (momentum is zero).
The same phenomenon is observed, when a boat is floating in a stream. The boat will be perpendicular to the stream.

48. Water level

By daily experience one knows that the surface of a liquid is horizontal, regardless of the shape and position of the container.
A container with a liquid (colored glycerin) is placed on an inclined rail. The container is held in position on the rail. *Observe how the surface of the liquid is horizontal.* The container is moved along the rail by hand. *Observe how even now the level stays practically horizontal.*
The container is placed at the top of the rail and is set free. It will slide down along the rail. *Observe how the surface of the liquid is no longer horizontal. Now it is parallel to the rail.*
This experiment is known as the experiment of Rodgers.

Explanation 1, 2: If the liquid is at rest, gravity acts on the liquid with a downward force. The basin exerts a force of the same value on the liquid, but in opposite direction. These two forces compensate each other and the fluid is at rest. The surface is always perpendicular to the force exerted by the container. This holds for any position of the container. There is physically no difference between a system at rest and a system moving with a constant velocity. When one moves the container along the rail by hand, involuntarily, the motion takes place for the most part, with a constant velocity. That is why the surface stays horizontal.
When the container is sliding along the rail on its own, the forces on the liquid do not cancel. The component of the gravitational force along the rail is used for acceleration of the liquid along the rail. Only the component perpendicular to the rail must be compensated by forces exerted by the container. These forces are also perpendicular to the rail and the surface of the liquid is parallel to the rail (again perpendicular to the force exerted by the container).

49. Tuning fork & stroboscope

A tuning fork is producing sound. One can hear and, sometimes, feel the vibrations. You can hardly see it. The legs of the fork move too fast. One merely sees it a bit hazy. A stroboscope is switched on. *Observe the apparent slow motion of the tuning fork.*

Explanation 1, 2: When a tuning fork is producing sound, its legs move back and forth (vibrate) at a constant pace (frequency). A vibration is a motion that is repeated frequently. A stroboscope is a flashlight that can be set to flash at the same pace as the tuning fork vibrates. In this case we see the tuning fork each time at the same position: it seems to stand still. If the pace of the flashlight is slightly different from that of the tuning fork, the illumination of the tuning fork takes place at subsequent slightly different positions: the tuning fork seems to vibrate slowly.
The same phenomenon is sometimes observed, when, for instance, spoke wheels are filmed.

52. Law of conservation of energy?

One of the fundamental laws in physics is that of the conservation of energy. When an object is dropped from a certain height, it can't rebound upwards to a greater height than its starting position. This is demonstrated by a weight (largest of the set) that falls down on a spiral spring that will cause the inversion of the motion. (The weight is guided along a long vertical rod, to keep it in vertical motion). One can see that the weight is rebounded to about 70% to 80% of the height of release.
On top of the largest weight another spring and a small weight is placed. The stack of the two weights and the spring in between is released from a certain height. *Observe how the small weight rebounds to a height that exceeds the original height a few times. Is the law of conservation of energy violated?*

Explanation 1: The large weight reaches the bottom first, whereas the smaller weight is still moving downwards. The two objects have a large difference in speed. On collision the speed of the smaller weight is nearly changed, so it will rebound with that speed and reach a greater height. The large weight will reach a somewhat lower height. So the law is not violated.

Explanation 1, 2: In the first experiment the weight only climbs up to about 70% to 80% of the height where it started from. Mechanical energy seems to be lost, but it is converted to another form of energy: heat.
In the second experiment mechanical energy seems to be gained, because of the great height that the small mass reaches.
When the stack is falling down, due to friction, the smaller weight is just slightly delayed. The larger weight is rebounded to an upwards motion, whereas the smaller weight is still moving downwards. The difference in speed between the two objects is nearly twice the speed at the end of the fall. So the two objects approach each other with high relative velocity and a collision takes place. When a small mass collides with a large mass, there is just a small amount of energy transferred to the small mass. This means that the speed of the small mass is just reversed (just like a tennis ball rebounds from a wall), relative to the large mass (which already was moving upwards). Of course, some energy is again lost by friction and some energy is exchanged between the two objects, to be seen at the slightly lower height that the large mass reaches. Our fundamental law has not been violated.

53. Liquid nitrogen & flowers & bananas

Liquid nitrogen has a temperature of −196 ºC. When organic materials are immersed in liquid nitrogen, it becomes extremely deep-frozen. The properties of these materials are changed dramatically. *Observe how flowers, normally lean and soft, can be crushed and how 'slimy' bananas can be broken into pieces by a blow of a hammer.*

Explanation 1, 2: The structure of matter changes under the influence of low temperatures. The structure becomes harder and more brittle (it will break rather than bend). Moreover, biological material contains a lot of water, that turns to ice, which is also very hard at such low temperatures.

54. Heavier than lead

A plastic bottle contains one liter of water. Water is very familiar to us. By daily experience we know what weight we may expect from this amount of water. *Ask a person in the audience to feel the weight of this water filled bottle by lifting it from the table*. A similar bottle contains the same amount of another liquid. *Observe the difference in weight!*

Caution: Don't lift the bottle higher than a few cm above the table and don't let the bottle slip out of your hands (the bottle might break)!

Explanation 1, 2: The mass of 1 liter of water is 1 kg. We are used to this mass because we know how a bottle of milk etc. feels like, when we hold it in our hands. The second liquid is mercury, a liquid metal. When we state that this second bottle contains the same amount of liquid, we obviously mean that the volume is the same. One experiences an astounding heavy weight.
The density of mercury is about 13.6 times greater than that of water, so, this bottle of mercury has a mass of 13.6 kg. The same volume of iron, a solid metal, would have a mass of 7.9 kg. Even lead is specifically lighter than mercury. One liter of lead has a mass of 11.4 kg. The mass of 1 liter of gold would be 19.3 kg and of platinum 21.5 kg.

55. Spheres of Magdenburg

Air seems to be virtually nothing: it cannot be seen; the density is very low; you can freely move your hands through it and hardly feel anything, etc. Yet, forces associated with air can be rather substantial.
Two hollow hemispheres (diameter about 10 cm) are placed against one another, with a rubber gasket in between, so that they form a whole sphere. A vacuum pump sucks out the air in the sphere. *Ask two people in the audience for assistance. Let them try to pull the two hemispheres apart.* (They will not – in general – succeed). Through a valve the air is gradually admitted to the sphere and suddenly the two hemispheres can be pulled apart. (Caution: let the people brace them selves, in order to not get hurt when the hemispheres come loose).

Explanation 1:
When there is no air inside the sphere, the atmospheric pressure is exerted on the outer surface of the sphere. The forces on this (small) surface exceeds mostly human strength. As air is admitted to the sphere, the air will also push from the inside. This results in a smaller total force.

Explanation 2:
When there is no air inside the sphere, the atmospheric pressure is exerted on the outer surface of the sphere. The effective surface of the sphere is about 75 cm^2. The atmospheric pressure is about 10 N/m^2, so the maximum force will be about 750 N (.75 kgf).
In free standing position, it is hard for people to pull will a force greater than 750 N.

56. How much does air weigh?

When one asks a person: "What is air?", many times this answer is heard: "Nothing, or virtually nothing". *Explain to the audience that air consists of small particles, molecules. Let the audience estimate how much the weight (mass) is of 1 m^3 of air.*
A glass bottle, that contains 1 liter of air, is placed on a balance. The weight is read from the display or scale.
The bottle is now evacuated and put on the balance again. The weight is read again.
Observe how the weight is diminished. The difference in weight, read from the scales, is about 1.3 g. When the air is admitted to the bottle again, the original weight reappears.

Explanation 1, 2:
At the first measurement the total weight of the bottle and air together is determined.
Then, by means of a vacuum pump, the air is taken out of the bottle. When the bottle is weighed again, only the weight of the bottle itself is measured. The difference in weight is the weight of the air that was in the bottle. In this measurement the result is: the weight (mass) of 1 liter of air is about 1.3 g. As 1 m^3 contains 1000 liter, the amount of air in a volume of 1 m^3 is 1000 times as much as in 1 liter. So 1 m^3 of air weighs about 1300 g, that is about 1.3 kg, which is rather substantial!
(In this explanation the words 'weight' and 'mass' are carelessly intermingled).

59. Boiling by cooling

The normal way to bring water to the boil is to 'put the kettle on', meaning: add heat to the water to raise the temperature to the boiling point. In this experiment water will be boiling not by heating it, but, on the contrary, by cooling it.
Water is poured into a vessel and is, in the conventional way, heated to a fairly high temperature (but under the normal boiling point). Then the heating is stopped and the opening of the vessel is shut off with a plug.
The vessel is cooled down by pouring cold water over it. *Observe how the water starts to boil.*

Explanation 1:
By heating the vessel, the space above the fluid is filled with hot water vapor. After sealing and cooling, the vapor pressure above the fluid drops quickly, while the fluid stays hot. Because of this low pressure above the fluid, the water starts to boil at a lower temperature than 100 EC.

Explanation 2:
Boiling of a fluid means that the pressure of the vapor is equal to (or slightly greater than) the pressure of the surroundings. In the case of boiling water, the pressure of the water vapor should be at least atmospheric pressure. Under normal atmospheric circumstances the temperature of the water must then be 100 EC.
When the pressure of the air above the fluid is lower than normal atmospheric pressure (like high up in the mountains), the pressure of the water vapor needs also be lower for the fluid to boil. This lower pressure of the vapor is achieved at likewise lower temperatures.
By heating the water in the vessel, the air in the vessel is superseded by water vapor of fairly high temperature, say about 95 EC. The water is not boiling at this moment.
When the vessel is taken away from the heat source and when it is sealed, no air or vapor can come in or out. The cooling of the vessel causes the pressure of the vapor to drop quickly to a low value (the vapor pressure drops much faster with decreasing temperature than a gas would do, i.e. much faster than according to a linear dependence). Because water fluid has a greater specific heat than water vapor, the temperature of the water is scarcely lowered.
Because of this temperature of the water, the vapor pressure in the water is higher than the pressure of the vapor above the water. This makes the fluid boil, although the boiling temperature is well below 100 EC.
In a pressure cooker the opposite occurs. By closing and sealing the lid, and by continuously heating, the vapor pressure can rise to a higher value, permitting a higher boiling temperature than 100 EC for the water. (The safety valve sets a limit for the pressure and the temperature).

63. Electric current & heat

A large aluminum ring is passed to the audience. Let the audience feel the normal temperature (surrounding) of the ring.
The ring is placed over an iron core of a coil. The coil is connected to the mains (230 V). The ring tends to climb up. The ring is held down by hand. The apparatus starts to hum and to vibrate. After a short while the experimenter must let go of the ring, because it has become hot. *Pass the ring again to the audience.*
The ring may be cooled down in water for further use.
Caution: - Don't let the ring get too hot (blisters on the fingers!)
Caution: - Permanently observe the temperature of the coil. This temperature must always be such that you can put your hand on it. Higher temperatures will destroy the insulation of the coil!
Give the coil time to cool down!

Explanation 1: The heat is produced by electric currents that flow in the ring.

Explanation 2: The coil, the iron core and the aluminum ring can be considered as a transformer. The ring acts as the secondary coil of the transformer. Although this coil consists of just one winding, the current can be very high, because of the low resistance of the ring. A transformer passes energy from the primary coil through the magnetic field to the secondary coil. The secondary coil is, so to speak, short-circuited and demands maximum energy from the system. The energy is converted to heat.

64. Communicating vessels (water hose)

When water is poured into a U-shaped water hose, the water reaches the same height on both sides. This result is generally expected. Now the hose is wound up a few times around a reel. Water is poured into one end of the hose. *Observe how the water level is different on both sides.*

Explanation 1: Think about that and you will understand how you can pour tea out of a teapot! When the pot is tilted sufficiently, the level of the tea in the nozzle exceeds the edge of the nozzle. Then the tea is poured out.
The wound-up hose forms no real communicating system, because some air is locked in.

Explanation 2: According to the law of the 'communicating vessels' the levels in both legs of the U-shaped water hose are the same. The water has free contact between the two vessels, and the same (atmospheric) pressure is exerted on both surfaces of the water.
When water is poured into the wound-up hose, this law of 'communicating vessels' will hold for as much as the first half loop of the hose is completely filled with water. When more water is poured in, the water will flow over the highest point of the loop and it will settle at the bottom of the next loop. At this moment an amount of air is locked up in the second half of the loop. When more water is poured in, that amount of air is compressed. One needs more pressure (higher water column) of the water that is poured in, to let the water pass the first loop. The same holds for the next loops.

65. Pump without moving parts

Ordinary water pumps always have some moving parts, for instance a rotor, or an eccentric. *Here one can see a pump at work that operates on heat as energy source.* Here the heat is provided by an electric wire. In full-scale applications heat of the sun is used (by means of mirrors). The only moving parts are the small glass balls in the valve, to regulate the flowing direction of the water.

Explanation 1, 2: This type of pump is also called a 'liquid piston' pump. Essential are the columns of water and air that are oscillating. Heating of the column of air at one side, cooling at the other side and a phase difference in motion of the water column at either side of the air column, provides a process that is similar to the Stirling process in a heat engine.

66. Draining

Two vessels contain the same amount of water. Each vessel has an outlet tube with a valve. The two vessels are identical, except for the length of the outlet tube. The first one has a length of about 60 cm. The outlet tube of the other one is about 5 cm.
Ask the audience which one of the two vessels comes first in becoming empty when the valves are opened at the same time.

Explanation 1: The water column above the longest tube is the highest. Therefore the water comes out more rapidly at this longest tube.

Explanation 2: One might think that the resistance that the water meets whilst flowing is greater in the longest tube. However, hydrostatic forces are far greater than these frictional forces. The water column above the longest tube is the highest. The hydrostatic pressure is greater at the end of the longest tube than at the end of the shortest tube. The water leaves the longest tube under greater force and with greater speed.

67. Fluorescent-tube-lighting without wires

Under normal circumstances electric lighting needs wires as power supply. Here a fluorescent-tube-lighting is presented that works without electric wiring. The tube is placed along a metal rail. Then the tube is touched by a plastic rod that is rubbed with a fur. *Observe how the tube is ignited by touching the tube with the plastic rod.*

Explanation 1: The energy needed for the production of the light is provided by a radio-transmitter. Particles in the tube are accelerated and by collisions they produce light.

Explanation 2: The metal is in fact an antenna which is coupled to a radio frequent transmitter by placing the end of this antenna in the vicinity of the transmitting antenna. Currents that flow through the antenna produce an electro-magnetic field in which the tube is placed. The rubbed plastic rod is electrically charged and it will induce charges in the gas in tube. These charged particles in the gas inside the tube will be accelerated by the field (high frequency oscillations). The particles in the gas will collide. As a result of these collisions radiation (mostly ultra violet) is emitted by the gas. When this radiation hits the material on the inner surface of the tube, visible light will be produced. Thus the energy needed for the light is provided by the electric field induced by the radio transmitter.

68. Just plain cans and electricity

By very simple means high electric voltage can be reached. This experiment is known as the Kelvin-experiment.
Water is running smoothly out of two taps. Two metal tubes are made of two cans by removing the lid and the bottom. The tubes are suspended under the taps, so that the water runs through each of the tubes. Beneath the tubes the water is collected into two other cans. The tubes and the cans are connected crosswise with electrical wires. The wires, in turn, are connected with two sharply edged nails. The nails are pointing towards each other and are about 5 millimeters apart. *Observe how, after a while, a small spark jumps between the nails.* The voltage between the nails can easily rise to a value of 10.000 V.

Explanation 1, 2: In nature there are always some free electric charges present. Spontaneously the cans and the tubes will be slightly charged. One can't predict what sign of charge a tube will have. Assume that the left tube is slightly positively charged. This means, because of the wiring, that the right can is also slightly positive. By influention the water jet at the left will be charged negatively. Essential in this experiment is that the water jet breaks up into drops just above the tube. So negatively charged drops of water fall into the left can. In this way the left can is charged negatively. Because of the wiring the right tube gets negatively charged. At the right-hand side positively charged drops will fall in the already positively charged can. The charges accumulate. The left tube will share the charge of the right can. The influention gets stronger because of the larger charges. The same story can be told over and over again. Each time more charges are added. The voltage over the nails (that were connected with the nails) rises, until it is sufficient to produce a spark.
To make a spark jump over a distance of 1 mm in air about 2000 V is needed.
If the nails are 5 mm apart, the voltage must be 10.000 V to make the spark flash.

69. Imploding cans

A can (beer or lemonade) is containing only a few drops of water. Over a gas burner the water is brought to boiling point. Then the can is dipped upside-down in a tank with water. *Observe how the can gets crushed.*

Explanation 1: When the water in the can is boiling, the space in the can is filled with hot water vapor. The dipping in the water cools the vapor down. The pressure of the vapor in the can decreases and the atmospheric pressure crushes the can.

Explanation 2: By boiling the water, the air in the can is replaced by hot water vapor. When the vapor is cooled down, the pressure drops to a very low value (considerably lower than would be the case when using hot air, as saturation pressures of water vapor at temperatures well below 100E C are rather low).
The can is cooled upside-down in the water. One might expect that the only thing that would happen is that water gets sucked into the can. Indeed some water is sucked in, but the fall of the pressure is so fast, that the water is too slow to enter the can in full extend. So the pressure stays low for a short while, giving the atmospheric pressure on the outside time to crush the can. When the cans would be made of sufficiently thick material, the only thing that would happen is that the cans would almost completely be filled with water, as the crushing could not take place.

70. Rising hair

A vdGraaff generator produces static electricity. On top of the metal sphere there is placed a plume of long thin pieces of paper. Once the machine is switched on, the pieces of paper rise. *Ask a member of the audience, with loose long hair, to assist you.*
First, discharge the machine by connecting the sphere with 'earth'. Then ask the person to stand on a block of insulating polystyrene and to take hold of the sphere. Tell the person not to let go of the sphere! Switch on the generator and ask the person to shake the head a little. The hair will rise, just like the paper plume. The person can admire him/herself in a mirror. Switch off the generator and let the electric charge leak away (this takes about 10 seconds). Then the person is free to let go of the sphere and to step aside.

Explanation 1, 2: In daily life one experiences static electricity quite often: combing hair, taking off clothes, shuffling over a carpet, etc. In a similar way the generator produces its electricity, while accumulating the charge. Depending on the circumstances, (humidity of the air, sharply pointed objects in the direct neighborhood) the potential difference between the earth and the sphere can easily reach up to 400.000 V. *You better tell this figure at the end of the experiment, as people might get frightened.*
The human body acts as an electric conductor. Electric charges (of the same kind) repel one another, so they are distributed over a conductor in such a way, that they take the most distant position from each other (energetically lowest positions). The pieces of paper and the hairs become also charged in this way. Charged objects (hairs) repel one another. That's why the hairs will rise.

75. Chatter-ring

The chatter-ring is a commercially available toy. It consists of a rod bent in the shape of a large ring, which can be held in the hand. A few smaller rings are strung as beads to the large ring. The skill of the game is to strike the small rings with the palm of the hand, so the small rings start to spin. *Observe the wobbling motion of the smaller rings, as the larger ring is held vertically and rotated slowly in the hand.*
In the case that not all the small rings are made to wobble, one can try to invoke such a wobbling motion by touching this ring with an already wobbling ring.

Explanation 1, 2:
When a small ring spins with its axis of rotation along the large ring, it will only spin, without the effect of wobbling. When the axis of rotation has a slightly different orientation, frictional forces between the large ring and the smaller ring become important. These forces change the axis of rotation, causing the ring to wobble.
At first, the rings are located at the bottom side of the large ring. Because of the friction, one can move the wobbling rings to another position on the large ring by rotating the large ring a little. One can bring the rings to a higher position. Due to gravity the small rings will descent along the large ring gaining kinetic energy. This kinetic energy is lost by the friction. But by continuously rotating the large ring, one can keep the small rings at the same position, so they seem to fall continuously. In this way the player continuously passes on energy to the small rings.

78. Hourglass

An ordinary hourglass (or sandglass) is placed in a transparent tube, made of glass or Perspex. The tube is filled with water and the tube is sealed at both ends. There is no air in the tube. The weight of the hourglass is chosen in such a way, that the hourglass is just slightly buoyant in the water. So, held vertically and at rest, the hourglass will be located at the top of the water column and only the lower compartment of the hourglass contains sand. The upper compartment is empty.
The cylinder will now be turned upside-down. The sand is now running downwards into the other compartment. *Observe how the hourglass will not rise in the water column.* At first, it shows no tendency to float. *Observe how after a while the hourglass is rising until it reaches the top of the cylinder again.*
Ask a physicist to explain this phenomenon.

Explanation 1: When the hourglass is turned upside-down, it will be top-heavy. It will lean against the wall of the tube. Frictional forces prevent the hourglass to rise.

Explanation 2: Many physicists are bothered by too much knowledge. The running of the sand distracts the attention from the real problem: when the tube is turned over, the hourglass is also upside-down. Initially, the upper compartment is filled with sand and the lower compartment is empty. Of course, the buoyant force on the hourglass is the same as before. But the difference is, that the center of mass (the point where the average downwards directed gravity force acts on) is located above the point where the average upwards directed buoyant force acts on. These two forces are in general not acting along the same line. They do not cancel out. They cause a momentum on the hourglass, resulting in rotation. The hourglass will lean against the wall of the tube. Frictional forces prevent the hourglass to rise until the position of the center of mass has lowered enough. In that case the momentum on the hourglass will be smaller, the leaning against the wall of the tube will be less and the frictional forces will decrease. The buoyant force may now overcome the friction.

81. Curved light beam?

Light beams always propagate along rectilinear paths. It can be demonstrated that a light beam emerging from a laser is a straight line over a considerable long distance.
In this experiment a light beam of a laser is traversing a fluid. *Observe how the path of the light beam is curved in the fluid.* Before entering the fluid, the light beam is rectilinear and after leaving the vessel, the beam is straight again.

Explanation 1: Normally, as we are used to it, light is propagating through a medium like air or water. In these media the light will propagate along a straight line. When light strikes the boundary surface between two of such media, reflection may take place. In this experiment the two media consist of two different transparent fluids. The separation surface is slightly disturbed, causing a gradual refraction and deviation of the light path.

Explanation 2: In homogeneous media light will propagate along straight lines. The air, before and after the fluid, is homogeneous, so the beams before and after the fluid are straight. The fluid consists of two components, water and glycerin. Glycerin has a greater density than water, so the bottom of the vessel contains glycerin and on top of this glycerin the water will float. The index of refraction is also greater for glycerin than for water. With a sharp boundary between the two fluids, total reflection will occur when the light beam hits this boundary surface from below (the light is shining from the glycerin upwards to the water). When the boundary surface is stirred up a little, a (optical) density gradient is formed, making the fluid no longer locally homogeneous. In this case, gradual refraction will take place, showing a curved light beam.
This phenomenon also occurs in the earth's atmosphere. The (optical) density differences in the air may be caused by temperature differences. Air can be heated by hot soil or road surfaces, or air can also be cooled by water surfaces, in both cases causing mirages. On a larger scale, density differences depending on the height in the atmosphere may cause disturbed observation of the setting sun, or they may cause aberrations in the observed positions of stars.
The light beam in the fluid is made visible by adding scattering particles (milk) to the fluid.

88. 3-D Illusion

Two concave mirrors are placed on top of each other, with the reflecting sides facing each other. A small object is placed on the bottom of the lower mirror. A hole is made in the center of the upper mirror. *Observe the 3-dimensional, non-inverted image of the object.*
This image seems so real, that one can hardly suppress the tendency of grasping at the image. One even seems to be able to 'touch' the image with a pencil.

Explanation 1: Light from the object is reflected twice by the mirrors, producing a non-inverted image. The 3-dimensional illusion is caused by the point by point projection of the object in the image.

Explanation 2: The two concave mirrors have the same focal lengths. The mirrors are placed on top of each other in such a way, that the focal points coincide with the reflecting surface of the opposite mirror. In other words, the centers of the reflecting surfaces have a distance equal to the focal length. (In the case of spherical mirrors with radius R, this distance is 0,5 R).
The small object is located near the focus of the upper mirror. Light emerges from a point of the object towards the upper mirror, which reflects this light as a nearly parallel beam back towards the lower mirror. This light, in turn, will be reflected upwards and converged into an image point near the focus of the lower mirror.
Points of the object near the reflecting surface, i.e. near the focal plane of the upper mirror, will be projected as an image near the focal plane of the lower mirror, i.e. the plane of the hole. Points of the object lying above the reflecting surface will be projected above the plane of the hole, thus forming an upright, non-inverted, 3-dimensional image.

90. Keep on rolling

A ping-pong ball is made electrically conductive. The ball is placed on an insulating tray with a conductive raised border. The border is connected to a high-voltage (low-) power supply.
Observe how the ball gets in an 'eternal' rolling motion.
The motion starts when the ball contacts the border. The ball will roll on 'for ever', as long as the high-voltage supply is connected to the tray.

Explanation 1:
Assume that the border is negatively charged by the power supply.
When the ball touches the border, negative charges are transferred to the ball. The tray on which the ball is rolling will be negatively charged by the ball. The charge on the ball and on the tray have equal signs. Equally signed charges are repellent, so the ball is pushed away.

Explanation 2:
Initially the ball is uncharged and the border is either positively or negatively charged, depending on the connection with the power supply. Assume for this explanation a negative charge on the border.
Because of electrical influention, the ball is attracted to the border. To put it in other words, the ball gets into a rolling motion and it gains kinetic energy. As soon as the ball touches the border, it will be negatively charged as well. The ball will be repelled slightly by the border, because of equally signed charges. The ball is a conductor and it will locally charge the tray on which it is rolling. The tray is an insulator, so the charge is localized (trapped) to that specific spot. This charge on the tray has also the same sign as the charge on the ball. The ball will also be repelled by the charge on the tray. As it already had a direction of motion, the ball will be propelled in that same direction, leaving a trace of negative charges on the tray. The repelling force by the tray is continuously present, but it is diminishing, since the ball loses charge to the tray.
As the charge on the ball is decreasing, the attraction by the border is increasing. When the ball touches the border again, the same procedure is started all over again. By the time the ball reaches the same spot on the tray again, the charges on the tray will be leaked away.
In this way the ball keeps on moving along the border.

91. Ping-pong match

(See also 37). Two sheets of a conductor (metal) are placed in a vertical position, parallel to each other and about 15 cm apart. A ping-pong-ball is covered with an electrically conductive coating. The ball is suspended from an insulating string, like a pendulum.
A high-voltage power supply is connected to the metal plates.
Observe how the ball is played continuously between the 'table-tennis bats'.

Explanation 1:
The metal plates ('bats') are electrically charged with opposite charges. When the ping-pong-ball touches one of the plates, it takes over part of its charge. Because charges of the same kind repel one another and opposite charges attract one another, the ball is pushed away by the plate it had just touched, and it is attracted towards the other plate. As soon as it touches the other plate, the ball takes over part of its charge. Now the ball is pushed away by this plate and the same procedure repeats over and over again.

Explanation 2:
The metal plates ('bats') are electrically charged with opposite charges. The plates act as a capacitor. Between the plates there is an electric field. When the ping-pong-ball touches one of the plates, it takes over part of its charge. In the electric field this charged ball experiences a force which is directed towards the other plate. The ball will hand over its charge to the other plate (which was oppositely charged), as soon as the ball touches this plate. But, moreover, this other plate will charge the ball with charges of its own kind. By the electric field the ball is pushed towards the first plate again, giving away its charge and gaining new, opposite charge. Now the same procedure repeats all over again. In this way the ball transfers charges from one plate to the other. The ball has become the means of transport for electric current.
The capacitor would be discharged completely and the motion of the ball would slow down and come to rest, if not the power supply maintained the charges on the plates.

92. High-Voltage Mill

A mill is made of a conductor (metal) and is connected to a high-voltage power supply.
Observe the perpetual spinning of the mill.

Explanation 1:
The power supply charges the sails of the mill. At the sharp edges of the sails the charges will leave the sails like a spray. By this spray of charges air particles will get charged. The sails and the particles in the air have the same type of charge. Because charges of the same type are repellent, the air particles and the mill push each other away.

Explanation 2:
The power supply charges the sails of the mill. There is an electric field around the mill. On locations where the curvature of the surface of a charged conductor is greatest, the electric field is strongest. So the strongest field is found near the pointed tips of the mill. Molecules in the air are ionized in this strong field: if the mill is negatively charged, electrons (negatively charged) are pushed away from the mill towards the molecules, which, in turn, get negatively charged as well. Or, if the mill was positively charged, molecules of the air are deprived from electrons because the positively charged mill exerts an attractive force on them. In both cases the air particles will gain the same type of electric charge as the mill. Equally signed charges are repellent, so the air molecules and the sails of the mill push each other away, causing the mill to spin.
The amount of charge on the mill is maintained, because of the power supply.
A lightning conductor uses the same principle of the strongest electric filed at the greatest curvature. A lightning conductor on a building is nothing more than a metal (copper) rod that is connected physically with the earth by a thick wire (the rod is electrically grounded). If there is a large electric field between the surface of the earth and the air (a cloud), the lightning conductor can force the lightning to strike itself, instead of the building. This is because, near the pointed edge, charges experience a stronger force and are thus accelerated more, creating an ionized path for the discharge of the lightning.

97. Twin cylinders

Two cylinders have identical appearances. They have the same diameter and the same length. The surfaces are equally polished. Even the mass is the same, which can be checked by placing the cylinders on a balance.
The two cylinders are placed on an inclined plane. They are released at the same time and, without slipping, they start to roll downwards.
Observe how one cylinder reaches the bottom of the incline faster than the other. Repetition of this experiment yields the same result for the same cylinder.

Explanation 1:
For any rolling object energy is needed for the rotation of the object. The amount of energy depends on the shape and mass-distribution of the object.
In this experiment the exteriors of the cylinders are the same, but internally the cylinders are different. One is a massive aluminum cylinder and the other is also an aluminum cylinder, but is made hollow. The removed material is replaced by a mantle of lead. Thus another mass-distribution in the cylinder is made, requiring more energy to rotate, resulting in a slower motion along the incline.

Explanation 2:
The difference in height between the initial positions of the cylinders and the bottom of the incline determines the amount of energy available for the motion of the cylinders. This motion is a combination of a translation (along the incline) and a rotation (around the axis of the cylinder). Because of frictional forces, the cylinder is forced to roll as it moves along the incline.
If the cylinders were truly identical, the ratio of translational and rotational energy would be the same for both cylinders. However, there is a difference between the cylinders: one cylinder is a massive aluminum cylinder, whereas the other is a hollow aluminum cylinder. A mantle of lead, having the same mass as the removed aluminum, is applied against the inner wall of the hollow cylinder. As lead has a larger specific weight than aluminum, there still remains a cavity around the axis of the cylinder. The mass distribution with respect to the rotational axis (= axis of symmetry of the cylinder) has changed in such a way that the moment of inertia has increased. An object with a larger moment of inertia requires more energy for rotation.
In this case, the rotation of the manipulated cylinder consumes more energy from the available amount of energy, leaving less for the translational kinetic energy. This makes the manipulated cylinder slower in descending the incline.

98. Good vibrations

A little bit of sand is spread out over a thin metal plate. By means of a bow of a musical string instrument (fiddlestick) the plate is made to produce sound. *Observe how the sand forms aesthetic patterns on the metal plate.* It depends on the skill of the performer, how many different patterns can be shown.

Explanation 1: The plate is made to vibrate. This means that the surface of the plate is moving up and down, but on the other hand, some places on the plate are at rest. Where the motion is the most fierce, the sand will drift aside towards the places at rest, thus forming nice patterns.

Explanation 2: The friction of the bow, in combination with the possible damping of a finger, will bring the plate into resonance. Standing waves are built up in the plate. When standing waves are maintained in a medium (metal plate) there are nodal points (no oscillation in the medium) and there are points with maximal oscillation. If present, the damping finger will force a nodal point in the plate. The sand grains on the nodal points of the standing waves are not affected, whilst the sand on the maximal oscillating points will bounce up and down, drifting towards the tranquility of the nodal points. When the finger is placed on another part of the plate and/or the bow acts on a different location, another frequency may be heard and/or another pattern may be seen. The patterns are called Chladni-patterns.

99. Chaos or order?

Two cylindrical vessels are mounted concentrically. The space between the cylinders is filled with a fluid. With an injection needle a 'thread' of dye is injected in this fluid.
The inner cylinder is rotated a few times. The 'thread' of dye is smeared out over the fluid and looks chaotic.
Then after a while the inner cylinder is rotated back again. *Observe how the shape of the thread is restored.*

Explanation 1, 2: The fluid can be considered as a system of thin concentric cylindrical layers. The layer closest to the inner cylinder will be taken along with the rotational motion due to frictional forces. The further away from the wall, the less the influence of the motion of the inner cylinder is. The layer closest to the outer cylinder, will be held on its original place. These shifting layers are responsible for the deformation of the colored 'thread'.
The fluid is glycerin, a substance with a fairly high viscosity. Because of this high viscosity, there will hardly be any turbulence disturbing the layer system in the fluid. Because the layer structure in the fluid is maintained, the original configuration can more or less be restored.

105. Which way?

A steel ball can be launched from an inclined rail. At the end of the rail the ball will roll over the surface of a turntable covered by a piece of paper. The ball is dipped into ink and it will leave a track on the paper. This experiment is divided into a few stages.

1. The turntable is held at rest. The ball is launched. *Observe that the track of the ball is a straight line.*
2. The end of the rail is positioned on the axis of rotation of the turntable, so the ball rolls away from the center of the turntable. The turntable is rotated clockwise. *Ask a person of the audience to predict the shape of the track of the ball.*
   Observe how the track is curved.
3. The position of the rail is kept the same, but the rotation of the turntable is now anti-clockwise. *Ask a person of the audience to predict the shape of the track of the ball in this case.*
   Observe how the track is curved opposite to the curvature in stage 2.

From now on the rotation of the turntable will be kept the same, say anti-clockwise, and the position of the rail is changed each time.

4. Position the rail in such a way that the ball rolls from the edge of the turntable towards the center. *Ask a person of the audience to predict the shape of the track of the ball in this case.*
5. Position the rail half-way between the center and the edge. Direct the rail along the direction of the rotation. *Ask a person of the audience to predict the shape of the track of the ball in this case.*
6. Reverse the direction of the rail, so that the ball will roll against the direction of the rotating turntable. *Ask a person of the audience to predict the shape of the track of the ball in this case.*

Explanation 1, 2: The turntable is a rotating system. The tracks we see on the paper are the same tracks as an observer would see, if he would take place on the turntable. He would then rotate along with the system and he would be at rest with respect to the turntable. The people in the audience don't rotate on the turntable. When one looks very carefully, one sees the ball rolling in a straight line in any of the above cases (laws of inertia). The observer on the turntable sees a curved track and he must conclude that there must be a force exerting on the ball. These type of forces are called 'subjective forces'. In this case the direction of this force and the deviation from the straight line is determined only by the direction of the rotation. So, any of the above cases having the same rotational direction, shows a curvature towards the same direction, with regard to the motion of the ball.

In daily life we experience the same type of subjective force (Coriolis-force), because we live on a rotating planet. On our Northern Hemisphere every motion will be affected in the way described above, except for motions along the equator. Winds, for example, have the tendency to deflect to the right-hand side. Also rails of trains wear out non-symmetrically, due to these forces. On the Southern Hemisphere the deviation is directed to the left-hand side.