

**PHYSICAL EXPERIMENTS
ON THE
AIR-CUSHION TABLE
U15420**

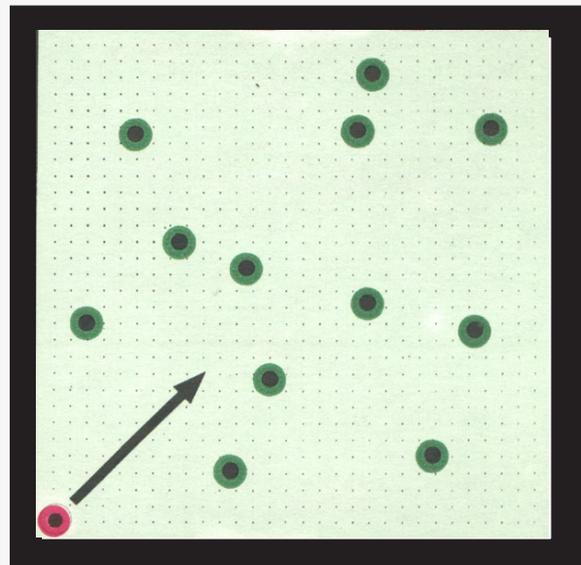
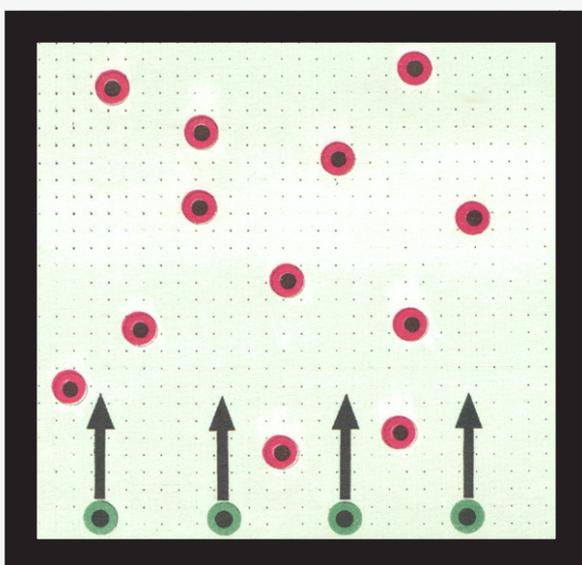


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Introduction

Air cushions are produced and sustained by means of air continuously emitted from jets in one of the objects as they move against one another. This prevents any contact between the two objects. As a “lubricant”, there is a thin gas cushion between them, similar to the oil film frequently used. Due to the much lower viscosity of the air, friction is reduced to negligible levels.

Using the air cushion makes it possible to conduct many experiments in a much better quality. A large number of experiments, however, are only possible by making use of the air cushion.

A disadvantage of the common two-dimensional air-cushion arrangement is limited visibility. To observe the motions in two dimensions, it is necessary to step up closely to the setup. Such systems are furthermore very difficult to handle because of complicated stabilization and adjustment procedures. The use of projection offers new opportunities. It allows both an expedient reduction in the size of all parts of the experiment setup and a considerable improvement in visibility.

Finally, mechanical collisions proved to be too inefficient. Since in this case only part of the energy is transmitted, it would have been necessary to take additional measures to compensate for the loss of kinetic energy. Making use of the forces between ceramic magnets allows the production of virtually fully elastic collisions. The fact that an immediate contact between the colliding partners does not occur is no disadvantage in most cases. This method is highly suited for model demonstrations, e.g. of the force relations on a microphysical level.

The gas cushion principle, use of projection and use of magnetic forces make the air-cushion table a high-quality teaching aid, characterized by simple operation, high reliability, universal usage and excellent methodological qualities. Some of the experiments basically cannot be carried out better with other currently known methods.

The air-cushion table is used mainly in model demonstrations of microphysical procedures. The characteristic vividness of models and the excel-

lent visibility make this demonstration a kind of “window into the microcosm”. However, it is necessary to mind the shortcomings and limits of modeling. Not only are the procedures highly simplified and represented in a purely mechanical way, also the motions of the real objects are in many cases determined by other forces. Furthermore, all procedures occur on one level. Finally, models contain additional misrepresentations, which become visible e.g. in the shape and color of the hover discs.

Due to the relatively high throughput of air and the small size of the hover discs additional driving mechanisms occur. The effect of these is that the motion of the small, hover discs will not stop as long as the airflow continues. This has the great didactic benefit that many processes can be observed for any required duration, without any need of intervention.

On the other hand, the limited force effect between the hover discs and between them and the magnetic barriers determines a specific maximum speed, which, in the case of very quick hover discs, has practically been reached already after one collision.

With the help of these mechanisms, optimal, well-visible motions usually begin by themselves. The driving mechanism increases the velocity; the not fully elastic collisions limit it.

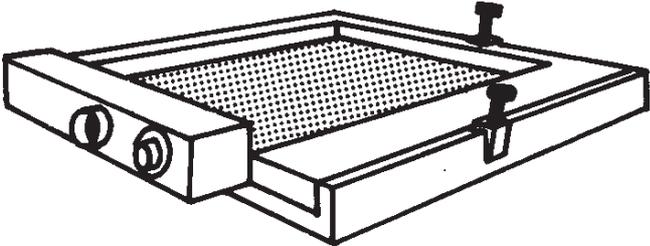
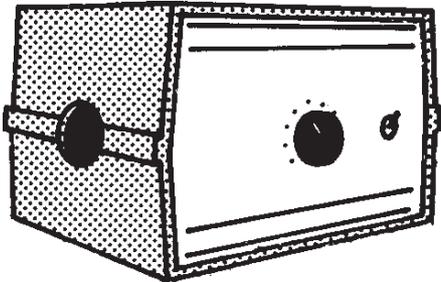
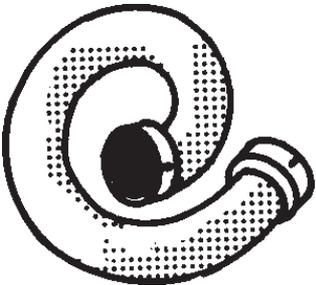
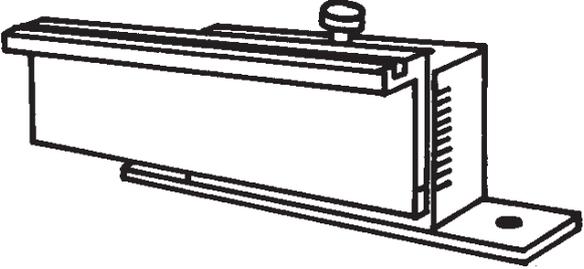
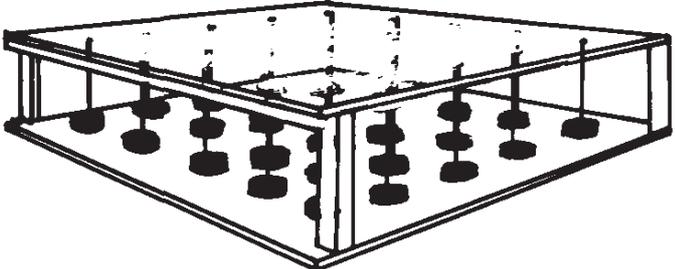
However, both mechanisms can also have an adverse effect by misrepresenting the motions of interest. Only the knowledge of these processes and their well directed usage or inclusion by the experimenter allow full utilization of the great potential of this valuable teaching aid.

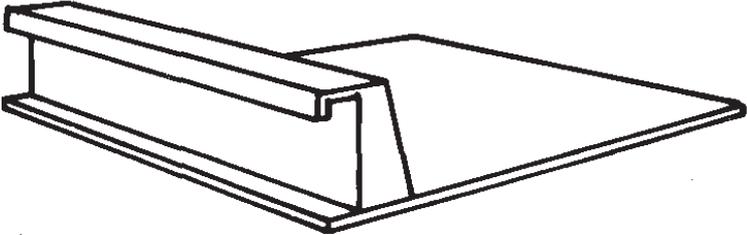
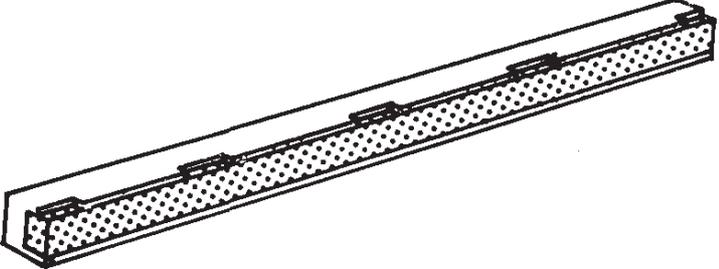
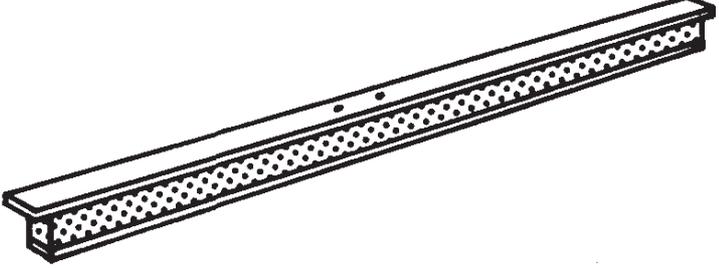
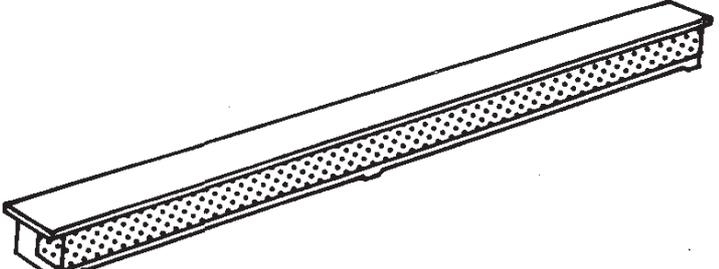
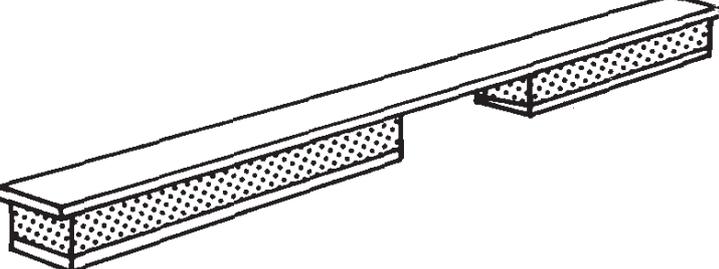
On the following pages you will find a description of the setup and possible uses of the air-cushion table. Then you will find instructions for conducting important experiments.

The illustrations are meant to assist you in your work. They are taken from the perspective from which the teacher views the experiment setup on the air-cushion table.

1. Setup and Possible Uses of the Air-Cushion Table

1.1 Components of the experimenting apparatus

<i>Item</i>	<i>Quantity</i>	<i>Drawing</i>
Air-cushion table	1	
Air source	1	
Tube	1	
Holding device	1	
Lattice model	1	

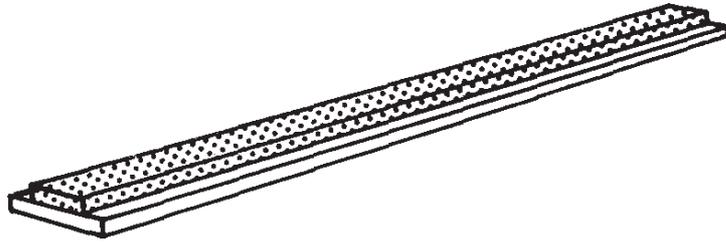
<i>Item</i>	<i>Quantity</i>	<i>Drawing</i>
Plexiglas plate	1	
Magnetic barrier 253 mm (no. 3 and no. 4)	2	
Magnetic barrier 233 mm (no. 2)	1	
Magnetic barriere 233 mm with slit for airflow from the side (no. 1)	1	
Magnetic barrier 233 mm with opening	1	

Physical Experiments on the Air-Cushion Table

<i>Item</i>	<i>Quantity</i>	<i>Drawing</i>
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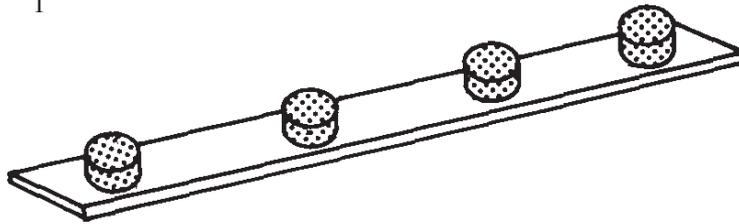
Flat magnetic barrier

1



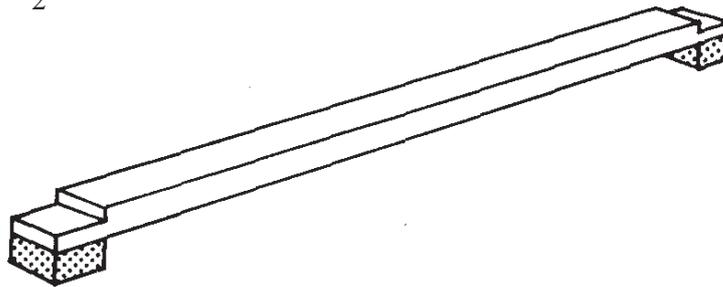
Magnetic barrier made of 4 magnets

1



Electrodes

2



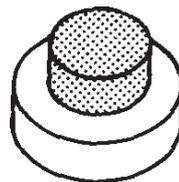
Manipulating rod

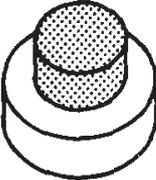
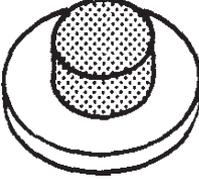
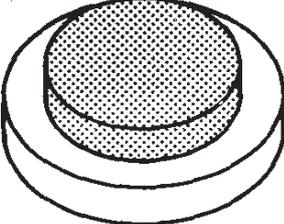
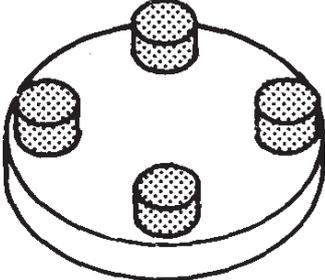
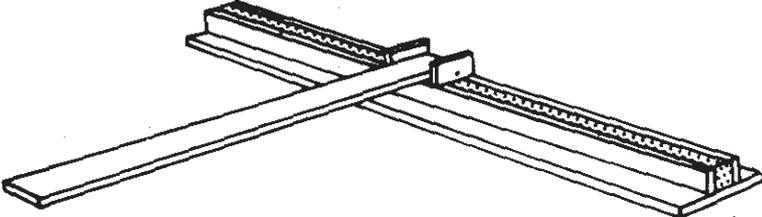
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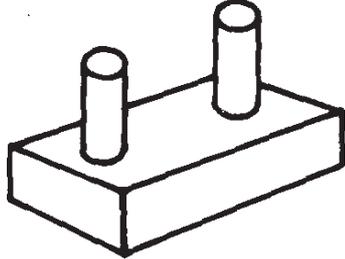
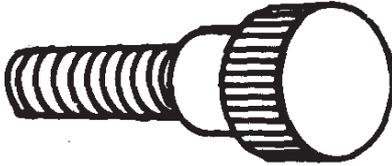
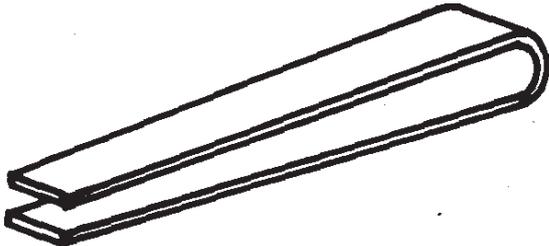
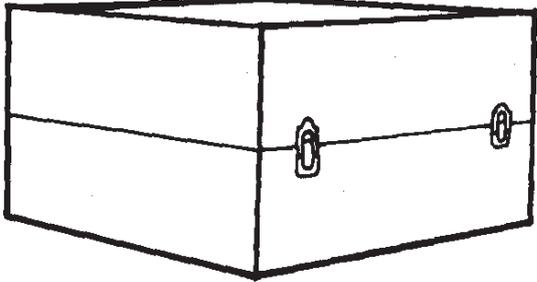
Magnetic hover disc
Ø 16 mm, red

30



Item	Quantity	Drawing
Magnetic hover disc Ø 16 mm, green	25	
Magnetic aluminum hover disc, Ø 21 mm	5	
Magnetic hover disc Ø 28 mm, orange	25	
Magnetic hover disc Ø 48 mm, blue	2	
Magnetic piston	1	

Physical Experiments on the Air-Cushion Table

<i>Item</i>	<i>Quantity</i>	<i>Drawing</i>
Guide piece for the magnetic piston	1	
Fastening screws for the holding device	2	
Plastic tweezers	1	
Aufbewahrungskasten	1	

1.2. Principle Uses of the Air-Cushion Table

The system kit allows for

- nearly frictionless movement of the hover discs
 - through the air cushion
- modeling the interactions between the microobjects and the field
 - through magnetic forces
 - through electrical forces
 - by tilting the experiment surface
- excellent visibility of all experiments
 - due to projection with the overhead projector
- little preparation work
 - due to clear and simple system setup
 - since only few adjustments required

The experimenter can continually adjust the influence factors and directly intervene in the experimental procedure.

All of this ensures a large variety of uses, preferably to demonstrate the behavior of individual microobjects or microobject systems. Therefore it becomes possible to create moving, vivid and highly simplified models of complicated physical objects and phenomena, which one cannot observe directly.

Some of the forces taking effect in model experiments vary considerably from those occurring between the real objects. In many cases, however, the force-distance relations are very similar, so that special attention only needs to be paid to them in quantitative experiments.

Despite this limitation, the air-cushion table is a versatile, effective and appealing teaching aid when handled by a qualified and methodologically skilled experimenter. When teachers have fully understood the operation of the system and follow the operating instructions for the system described below, they can demonstrate experiments with physically convincing and effective results.

1.3. Setup of the Air-Cushion Table

The air-cushion table is made up of a frame and a pressure chamber. The cover plate of the pressure chamber has 1089 holes (\varnothing 0.8 mm). This is the experiment surface. The side of the pressure

chamber where the impulse valve is located is connected to the fan using the tube. The experiment surface can be set to the horizontal or inclined position by means of two adjusting screws.

Five different types of hover discs are supplied with the air-cushion table. They are made of colored, transparent plastic or aluminum discs, onto which cylindrical, ceramic magnets are attached. Carried by the air cushion, these hover discs simulate the moving objects.

The experiment surface is delimited by a flat plastic frame. It is also possible to attach magnetic barriers allowing for almost fully elastic collisions of the hover discs. Therefore it becomes possible to demonstrate interactions with the vessel walls.

To create an electric field, two rod-type electrodes can be placed on the experiment surface. A model effect of an electric field can also be attained by inclining the air-cushion table to the desired degree.

The impulse valve can be used to create an airflow parallel to the experiment surface influencing the motion of the hover discs. This can be used to increase the speed of the hover discs.

The fan ensures a sufficient air cushion over the experiment surface. Its performance is continuously adjustable and can be adapted to the conditions of the experiment. The fan is equipped with a delivery connection and a suction connection. While experimenting with the air-cushion table, the delivery connection is used, the suction connection can be used for other physical experiments (e.g. with the transparency panel apparatus).

The lattice model is made up of 25 ceramic magnets, which are suspended by thin steel wires. This system oscillates with little absorption. It is used to demonstrate e.g. the interaction of a metal lattice with the moving charge carriers as a model. It is inserted into the holding device in the same way as the Plexiglas plate. The height in which these components are located above the experiment surface can be adjusted as individually suited for each experiment by means of the setscrew. The settings can be easily reproduced using the scale marks.

1.4. Instructions for Usage

The air-cushion table is placed onto the overhead projector so that the arrow on the pressure chamber points to the projection screen. The magnetic barriers (fig. 1) are placed onto the air-cushion table so that their numbers (no. 1 to no. 4) match the markings at the edges of the experiment surface. The magnetic barrier with the slit at the bottom is arranged at the side of the table where the tube of the fan connects. The air flows through the slit and over the experiment surface when activating the impulse valve.

The pressure chamber and the fan are connected by the tube (fig. 2). The tube should run as straight as possible. Only one position is possible when connecting it to each of the devices. This is why both ends of the tube and the connectors of the devices are marked with a line. The tube is connected to the device so that both lines meet. Then it is turned slightly to the right or to the left.

Next, the experiment surface is aligned horizontally by means of the adjusting screws at sides 2 and 4 by means of the spirit levels.

When needed, the impulse valve is pressed several times for approx. 1 second. The fan has to be set to a sufficient performance level, since otherwise the pressure of the air cushion is too low and the hover discs will sink onto the experiment surface.

To install the lattice model, the holding device is screwed onto the frame of the air-cushion table. The lattice model is then inserted into the groove of the holding device (fig. 3) The influence of the lattice model on the motion of the hover discs

strongly depends on the height of the lattice over the experiment surface. The holding device, which is marked with a scale (fig. 4) can be infinitely adjusted to the appropriate height using a setscrew.

This allows for demonstrations of the behavior of conductors, semi-conductors and insulators.

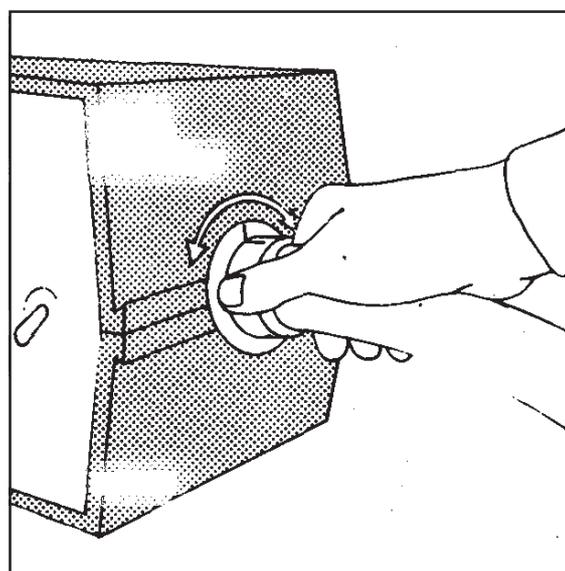
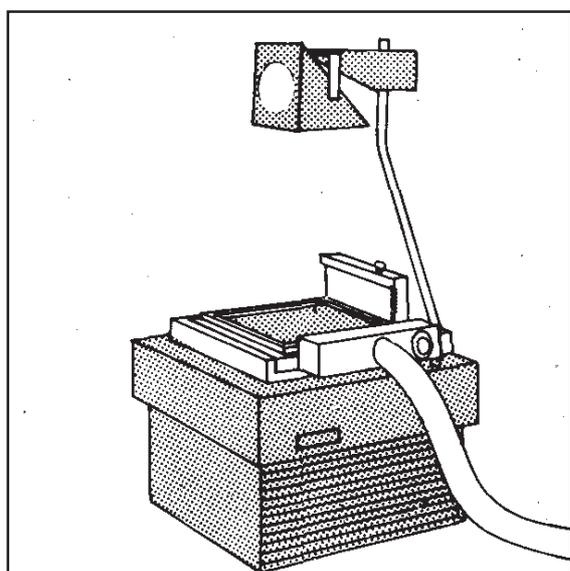
The electrodes are used to create an electric field. They can be applied in two positions. Placing them onto their base will create a gap between the experiment surface and the electrodes. This gap is large enough for the aluminum hover discs to fit through. These are then charged in accordance with the polarity of the respective electrode. The electrodes can also be turned around so that their bases point upwards. Then the aluminum parts touch the experiment surface and the hover discs contact the electrodes.

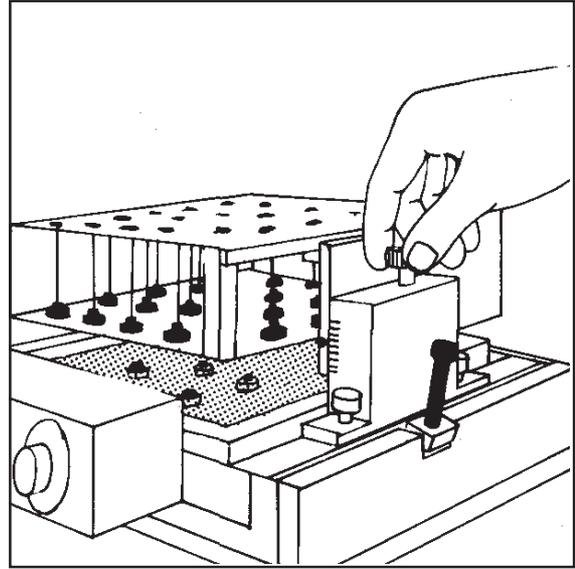
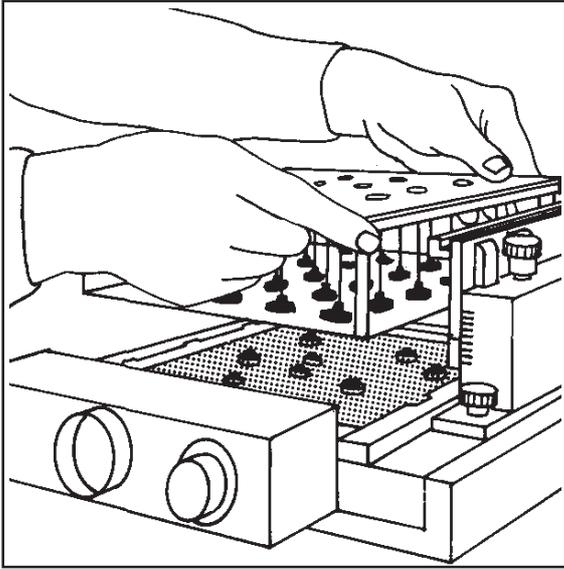
The voltage applied should be over 20 000 V. When the voltage is lower, the electrodes have to be arranged closer to each other.

An especially well-suited voltage source is the electrostatic generator.

The influence of the electric field on the motion of the hover discs can also be demonstrated by slightly tilting the experiment surface. The degree of inclination then corresponds to the strength of the electric field.

The strength of the fan is adjusted until the hover discs just begin to move freely. This ensures a relatively low level of noise. When the airflow is stronger, disturbance caused by the noise of the fan cannot be avoided. For this reason, it should





be positioned behind the experimenting table or inside it. This will reduce the noise level reaching the classroom. Further noise reduction can be reached by wrapping sponge rubber around the fan or lining it with Piatherm or the like. Special care should be taken, though, to ensure that the air can enter the suction nozzle unimpeded.

1.5. Maintenance and Care

The air-cushion table is a high-quality apparatus, which requires special care. Its stability has certain limits because of the consistency of the necessarily transparent material.

- Avoid damage caused by dropping, hitting, bumping, dragging or sliding.
- Keep all parts clean and free from dust.
- Remove dust with an anti-static cloth. Strong rubbing of the table surface causes electrostatic charging which may considerably affect the experiments.
- To keep the pressure chamber clean, do not place the airflow generator near dust accumulations.
- Keep the bottom sides of the hover discs clean at all times. They can be easily cleaned using ethyl alcohol.

2 Description of the Experiments

2.1 Structure and Properties of Gases

2.1.1 Motion of a Molecule in High Vacuum

Components:

Air-cushion table with fan	
Overhead projector	
Magnetic barrier, long	2 Pieces
Magnetic barrier, short	2 Pieces
Hover discs	1 Piece

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion table
Walls of the vessel	Magnetic barriers
Gas molecules	Hover discs

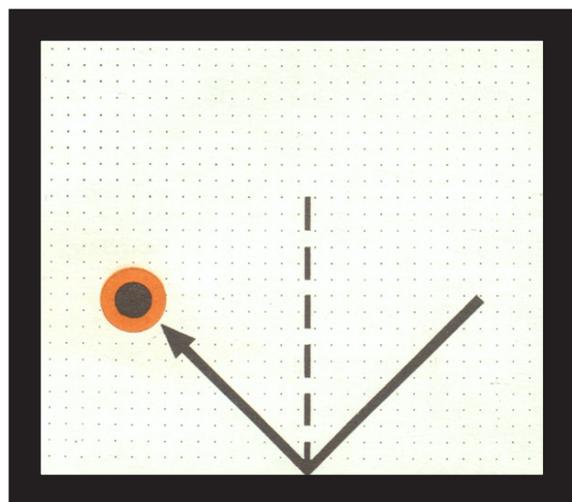
How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers.

Turn the fan to a medium setting. Place the hover disc onto the experiment surface and give it an impact so that it hits a magnetic barrier in the middle at an angle of 45° .

Result:

The motion of the hover disc is straight and uniform. When it hits a barrier, the direction of its motion changes. The speed is unchanged. The hover disc rebounds at the same angle at which it hits the barrier. The law of reflection applies.



Interpretation:

The gas molecule moves in accordance with the laws of classical mechanics.

2.1.2 Motion of the Molecules in a Gas

Components:

Air-cushion table with fan	
Overhead projector	
Magnetic barrier, long	2 Pieces
Magnetic barrier, short	2 Pieces
Hover disc, red	16 Pieces

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion table
Walls of the vessel	Magnetic barriers
Gas molecules	Hover discs

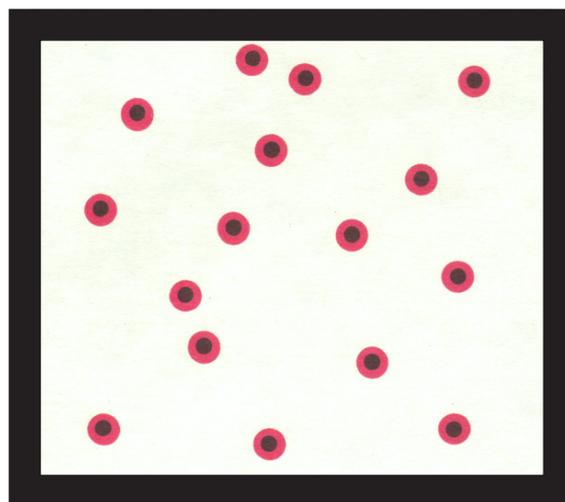
How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers.

Place the 16 red hover discs anywhere on the experiment surface so that the spaces between them are approximately 1 cm. Then turn the fan to a setting in which all hover discs are sure to lift off.

Result:

Each hover disc moves in a straight and uniform way as long as it does not hit any other hover disc or a magnetic barrier. When two hover discs collide, their speed and direction of velocity usually changes. These collisions cause a transmission of kinetic energy. When hitting the magnetic barrier, only the direction of velocity changes.



Interpretation:

Elastic collisions occur between the molecules of a gas and when molecules hit the vessel wall. Along the distance covered between two collisions, the "free length of path", the motion of the molecules is straight and uniform.

Note:

This experiment can be developed from the one described above in 2.1.1. by placing three additional orange hover discs onto the experiment surface one after the other while keeping the fan turned on. The collisions between the discs and the transfer of kinetic energy caused by them can be especially well observed when using a low number of discs.

2.1.3 Dependence of the Number of Impacts with the Vessel Wall on the Velocity of the Molecules

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Hover discs 2 Pieces
- Stop watch or master clock 1 Piece

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion table
Walls of the vessel	Magnetic barriers
Gas molecules	Hover discs

How to proceed:

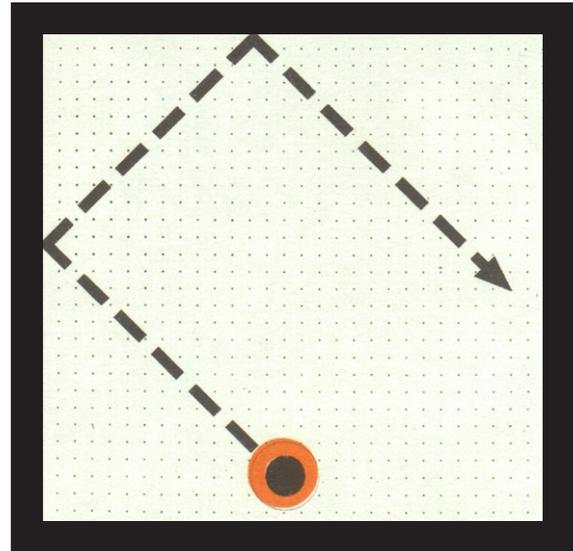
After aligning the air-cushion table horizontally, attach the magnetic barriers. Turn the fan to a setting in which two hover discs placed above each other are sure to lift off. Give this doubled hover disc an impact so that it hits one of the barriers in the middle at an angle of 45°. Count the impacts with the wall occurring within a given period of time (10 seconds). Then repeat the experiment with only one of the hover discs at a higher velocity.

Result:

The higher the velocity of the hover disc is, the more often it will hit the magnetic barrier within a specific period of time.

Interpretation:

The higher the velocity of the molecules is, the more impacts of the gas molecules will occur with the vessel wall. Since these impacts cause the pressure, higher molecule velocities cause higher pressure.



Note:

The hover disc can also be set into motion so that it hits the barriers at a perpendicular angle.

2.1.4 Dependence of the Number of Impacts with the Vessel Wall on the Volume

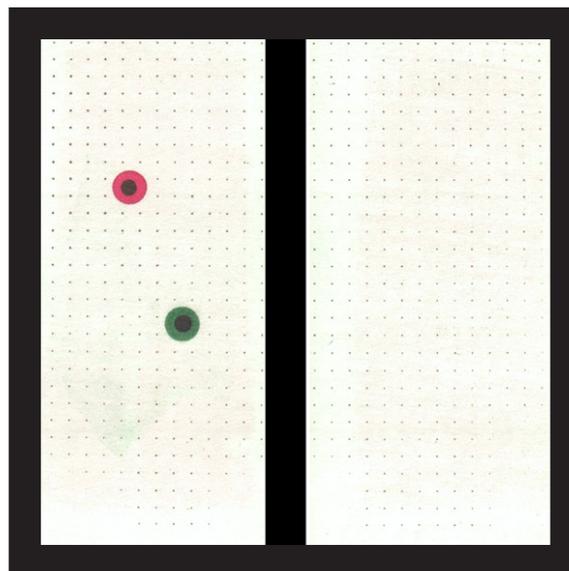
Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Hover disc, red 1 Piece
- Hover disc, grün 1 Piece
- Stop watch or master clock

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion table surrounded by magnetic barriers
Walls of the vessel	Magnetic barriers
Gas molecules	Hover discs

How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers. Turn the fan to a setting in which the hover discs are sure to lift off. Then place both hover discs into one corner of the experiment surface, first holding them with two fingers and then quickly releasing them. Count the number of impacts one of the discs performs with the vessel walls within a specific period of time (5 seconds).



Then reduce the area available for the hover discs to half its size. To do this, lift up magnetic barrier no. 2 and reattach it so that it separates the experiment surface into two halves, with its ends snapping into the recesses provided in barriers no. 3 and no. 4. Now set both hover discs into motion in the same way. Count the number of impacts one of the hover discs performs with the magnetic barriers within the same period of time as in the previous experiment.

Result:

In the first experiment, the number of impacts with the barriers is lower than in the second. By reducing the area to half its size, the number of impacts increases to approximately the double amount.

Interpretation:

Reducing the volume of a vessel containing a gas causes an increase in the number of impacts of the gas molecules with the vessel walls within a specific period of time. Since the number of impacts occurring in a specific period of time with a specific wall is an indicator of pressure, the conclusion is that reducing the volume increases the pressure.

Note:

Evaluation is easier when counting only the impacts with magnetic barrier no. 2 in each of the experiments. This, however, requires longer times of measurement.

It is also possible to ascertain the total amount of impacts of both discs. In this case it is recommended that one student counts the impacts of the red disc while another student counts those

of the green. The results are then added up.

2.1.5 Mean Velocity of the Molecules – Temperature of a Gas

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Hover discs, red 16 Pieces

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion table
Walls of the vessel	Magnetic barriers
Gas molecules	Hover discs

How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers.

Position all hover discs in one corner of the experiment surface so that the spaces between them are approximately 1 cm.

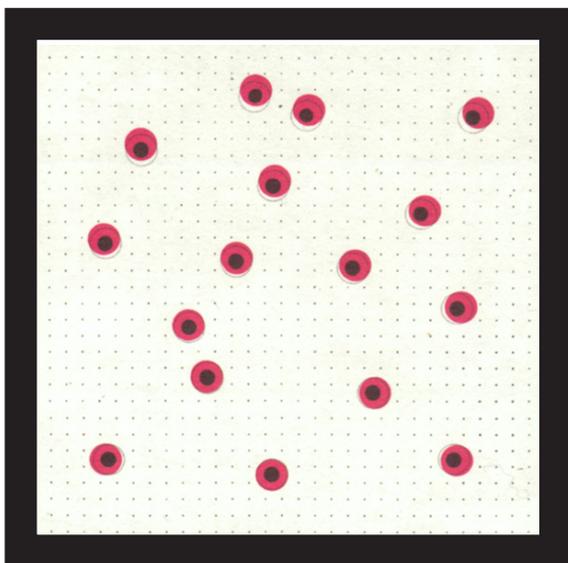
The fan is turned to a medium setting. Sequentially observe the motions of each of the hover discs. Draw attention to the velocity of each disc in relation to the velocity of all other discs. Gradually turn down the fan so that all hover discs come to a stop and then turn it up again so that they are sure to lift off. The same observations are repeated at a lower velocity.

Result:

The velocity of each hover disc changes with each impact. While an impact with the vessel wall

causes only a change in direction, a collision of two hover discs usually causes a change in speed as well.

At any given point in time, the majority of the hover discs move at a mean velocity. Only few hover discs have a high and few a very low velocity.



Interpretation:

The molecules in a gas have different velocities. The velocity of each gas molecule changes with each impact. Many molecules move at a velocity that is close to the mean velocity. Only few molecules have a very low or high velocity. The distribution of velocity is constant over time in a large number of molecules. The mean kinetic energy of the molecules characterizes the temperature of the gas. A low mean kinetic energy corresponds to a low temperature, a large mean kinetic energy to a high temperature. In each case there are molecules whose velocity is very low and others which are especially fast.

Note:

To ensure better visibility of the motions of a specific hover disc, use 15 red hover discs and 1 green one rather than 16 red ones.

2.1.6 Mean Velocity of the Molecules – Influence on Foreign Molecules

Components:

Air-cushion table with fan	
Overhead projector	
Magnetic barrier, long	2 Pieces
Magnetic barrier, short	2 Pieces
Hover disc, green	12 Pieces
Hover disc, red	1 Piece

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion table
Walls of the vessel	Magnetic barriers
Gas molecules	Green hover disc
Foreign gas molecule	Red hover disc

How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers. Closely arrange the green hover discs in one corner of the experiment surface so that the spaces between them are approximately 1 cm.

Turn up the fan so that all hover discs are sure to lift off.

Place the red hover disc in the middle of the experiment surface, holding it with the finger and then releasing it so that it is not in motion at first. Observe the motion it subsequently performs.

Then place the red hover disc directly into one corner of the experiment surface, holding it with the pointer and then quickly releasing it so that it moves in the direction of the center at high velocity.

Result:

In the first experiment, the red hover disc repeatedly receives impacts from the green discs. Its motion then no longer differs from that of the others. In the second experiment, the velocity of the red hover disc is reduced by collisions with the green ones, so that its motion then also corresponds to theirs.

Interpretation:

If a foreign gas molecule penetrates into a gas it cannot continue in its state of motion. The interaction with the other gas molecules adapts its motion to theirs after a short time.

2.1.7 Velocity of Molecules in a Gas Compound

Components:

Air-cushion table with fan	
Overhead projector	
Magnetic barrier, long	2 Pieces
Magnetic barrier, short	2 Pieces
Hover disc, red	12 Pieces
Hover disc, orange	2 Pieces

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion
Walls of the vessel	Magnetic barriers
Partition	Magnetic piston
Gas molecules	Hover discs

How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers. Divide the experiment surface in half using the magnetic piston, parallel to the barriers nos. 1 and 2. For guidance of the piston rod, place the guide piece for the magnetic piston onto barrier no. 2.

Place two hover discs into each half.

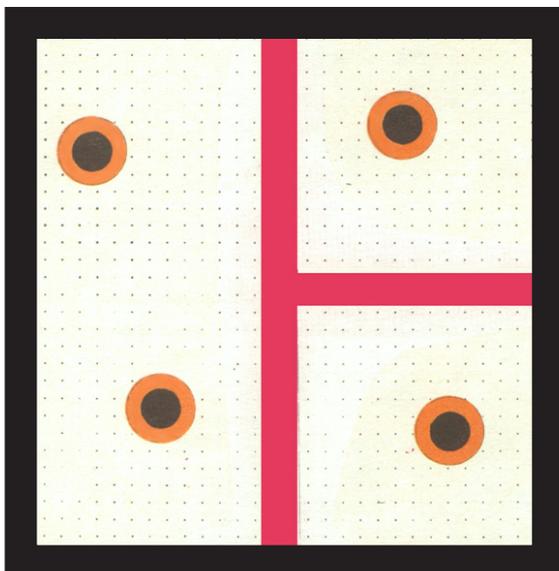
Increase the fan setting so that both hover discs are sure to float even when the impulse valve is opened. Open the impulse valve repeatedly in order to set the hover discs in the adjacent half of the experiment surface into strong motion, while ensuring lesser motion of the other two discs, if necessary by slowing them down manually. Now quickly remove the magnetic piston from the experiment surface and observe the motion of all hover discs.

Result:

The fast discs partially transfer their energy onto the slow ones. The mean velocity of all four hover discs is lower after the removal of the piston than the velocity of the two fast discs in the one half and higher than that of the two slow ones in the other half.

Interpretation:

When mixing two gases of different temperatures,



the resulting temperature is between the two initial temperatures. The reason for this is that the molecules of the gas with the higher temperature transfer part of their kinetic energy to the molecules of the gas with the lower temperature.

Note:

The experiment can also be carried out with 8 green and 8 red hover discs. This is a better demonstration of the conditions in a gas due to the larger number of hover discs. However, it is more difficult to maintain the difference in velocity. For this reason, it is necessary to (manually) accelerate the hover discs in one half and to slow them down in the other.

2.1.9 Increase of Temperature in Gases when Supplying Energy

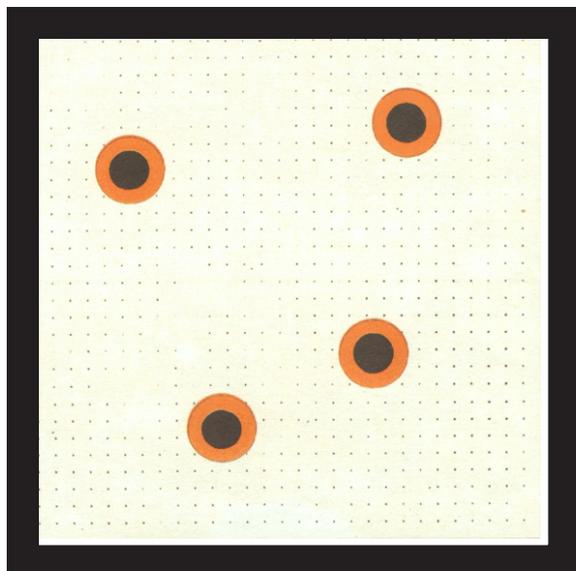
Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Hover disc, red 12 Pieces
- Hover disc, green 4 Pieces

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion
Walls of the vessel	Magnetic barriers
Gas molecules	Red hover disc
Molecules with higher energy	Green hover disc

How to proceed:

After aligning the air-cushion table horizontally,



velocity of the molecules and the number of impacts. The temperature and pressure of the gas increase. When expanding a gas adiabatically, the mean velocity of the molecules decreases and there is a drop in pressure and temperature.

2.1.12 Dependence of the Pressure on the Temperature

Components:

Air-cushion table with fan	
Overhead projector	
Magnetic barrier, long	2 Pieces
Magnetic barrier, short	2 Pieces
Magnetic piston	1 Piece
Guide piece for magnetic piston	1 Piece
Hover discs	8 Pieces

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion table surrounded by the magnetic barriers and the magnetic piston
Walls of the vessel	Magnetic barriers
Piston limiting the volume of the gas	Magnetic piston
Gas molecules	Hover disc

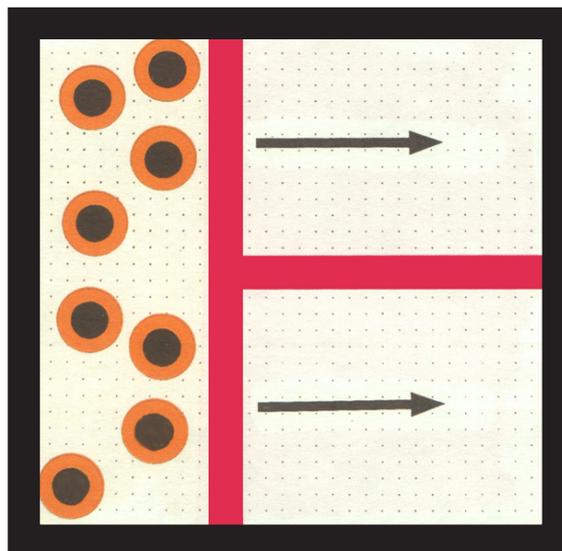
How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers. Place the piston on the experiment surface parallel to magnetic barrier no. 2. To provide a lateral boundary for the piston rod and to ensure its successful guidance, place the guide piece for the magnetic piston onto barrier no. 2. Place the hover discs onto the experiment surface near barrier no. 1 with the slit for the airflow entering the experiment surface from the side. Move the piston towards this barrier as far as possible.

Turn the fan to a setting that provides a strong airflow. Increase the mean velocity of the hover discs by repeatedly opening the impulse valve for a short period. Observe the motions of the hover discs and the piston.

Result:

The piston shifts through the impacts of the hover discs at the rate at which the mean velocity of the hover discs rises. This causes an enlargement of the area available to the hover discs.



Interpretation:

Increasing the temperature of a gas causes a rise in pressure when the volume is constant. If the vessel containing the gas is equipped with a moving piston, a rise in temperature will increase the volume of the gas.

Note:

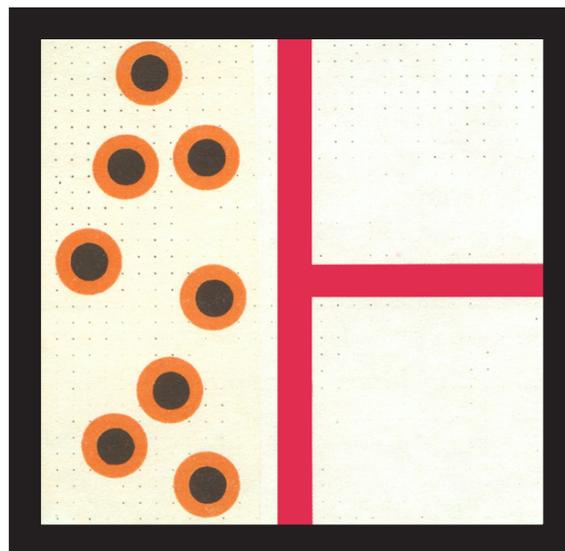
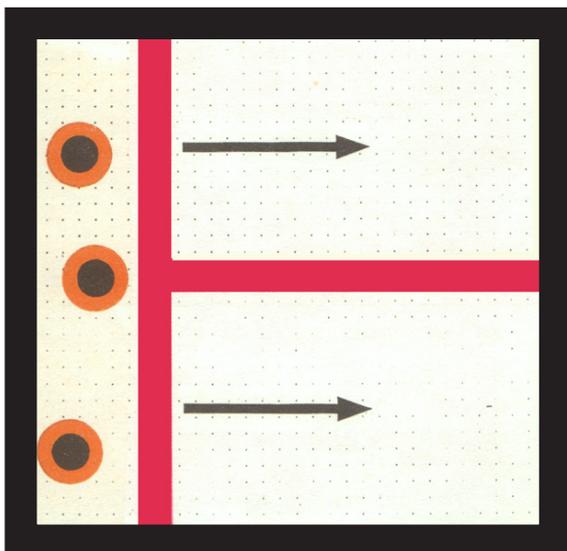
The force acting on the piston from the outside due to air pressure can also be demonstrated in this experiment by slightly tilting the experiment surface so that the hover discs have to push the piston up a slope.

2.1.13 Dependence of the Pressure on the Number of Molecules

Components:

Air-cushion table with fan	
Overhead projector	
Magnetic barrier, long	2 Pieces
Magnetic barrier, short	2 Pieces
Magnetic piston	1 Piece
Guide piece for the magnetic piston	1 Piece
Hover discs	8 Pieces

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion table surrounded by the magnetic barriers and the magnetic piston
Walls of the vessel	Magnetic barriers
Piston limiting the volume of the gas	Magnetic piston
Gas molecules	Hover disc

**How to proceed:**

Align the air-cushion table horizontally and attach the magnetic barriers around the experiment surface. Arrange the piston parallel to magnetic barrier no. 2. The piston rod rests on the guide piece for the magnetic piston, which has been attached onto magnetic barrier no. 2 and ensures its guidance. Arrange three of the hover discs near barrier no. 1, the barrier with the slit for air entering from the impulse valve. Move the piston as far as possible towards this barrier.

Turn the fan to a setting providing a strong airflow. Now bring one of the remaining discs after the other onto the experiment surface, making each shoot in at the highest possible speed starting from barrier no. 1. Observe the motions of the hover discs and the piston.

Result:

The piston shifts through the impacts of the hover discs at the rate at which the number of discs increases. This causes an enlargement of the area available to the hover discs.

Interpretation:

Increasing the number of molecules in a specific gas volume causes a rise in pressure. If the vessel containing the gas is equipped with a moving piston, the volume of the gas will increase when the number of molecules rises.

Note:

It is also possible to demonstrate the force acting on the piston from the outside due to air pressure. This is done by slightly tilting the experiment surface so that the hover discs have to push the piston up a slope to increase the area in size.

2.1.14 Diffusion of Gases**Components:**

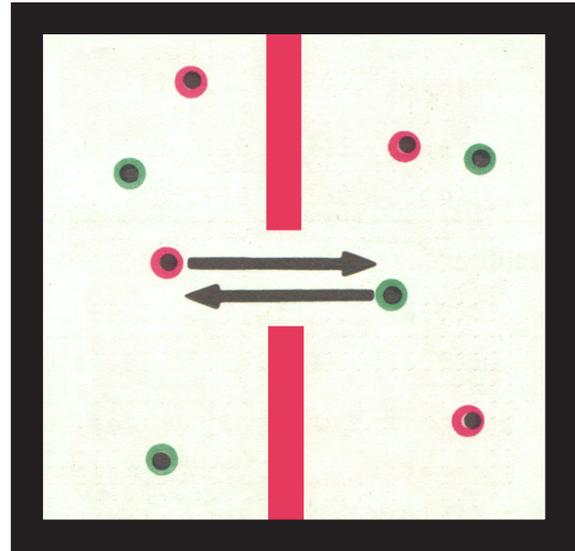
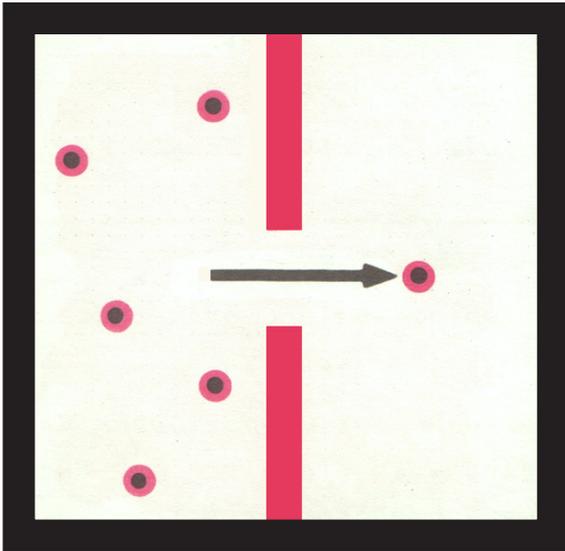
Air-cushion table with fan	
Overhead projector	
Magnetic barrier, long	2 Pieces
Magnetic barrier, short	2 Pieces
Magnetic piston	1 Piece
Hover disc, red	6 Pieces
Hover disc, green	6 Pieces

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion table
Walls of the vessel	Magnetic barriers
Partition	Magnetic piston
Molecules of one gas	Green hover disc
Molecules of the other gas	Red hover disc

How to proceed:

Align the air-cushion table horizontally and insert the magnetic barriers. Place the red discs in one half of the experiment surface, near magnetic barrier no. 1, and the green discs in the other half, near barrier no. 2. Place the magnetic piston in the center as a partition running parallel to barriers no. 1 and 2.

Turn the fan to a low setting so that the hover discs just lift off. Then quickly remove the piston and observe the motions of the red and green discs. Repeat the experiment using a stronger airflow after placing the red discs close to barrier no. 1 and the green ones close to barrier no. 2.



in the other.

After turning the fan on, observe the movement of the hover discs through the opening. Increase the mean velocity of the hover discs by repeatedly opening the impulse valve for a short time.

Result:

In all experiments hover discs move through the opening at irregular intervals. As a result in the first two experiments, each half contains approximately the same amount of discs after some time. In the last experiment the hover discs penetrate the opening in both directions, so that both types of discs mix. These procedures will occur more rapidly the higher the mean velocity of the hover discs is.

Interpretation:

The molecules of a gas can penetrate a porous partition. If the gas is initially contained in one chamber of a vessel with a porous partition, the diffusion through the partition causes an equalization of pressure so that eventually both chambers contain the same amount of molecules. If the two chambers of a vessel divided by a porous partition contain different gases, these gases will mix through the partition. Diffusion will occur more rapidly the higher the temperature of the gases is.

2.1.16 Brownian Motion in a Gas

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Hover disc, red 16 Pieces
- Hover disc, blue 1 Piece

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion
Walls of the vessel	Magnetic barriers
Gas molecules	Red hover discs
Particle showing the Brownian motion	Blue hover disc

How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers around the experiment surface.

Arrange the red discs near the magnetic barriers of the air-cushion table. Place the blue disc at the center of the experiment surface.

Set the fan to a medium setting. Observe the motions of the blue disc.

2.1.18 Local Distribution of the Molecules in a Gas

Components:

Air-cushion table with fan	
Overhead projector	
Magnetic barrier, long	2 Pieces
Magnetic barrier, short	2 Pieces
Manipulating rod	1 Piece
Hover disc, red	4 Pieces
Stop watch or master clock	

Model simulation	
Real Object	Model
Vessel containing the gas	Experiment surface of the air-cushion
Walls of the vessel	Magnetic barriers
Halves of the vessel	Halves of the experiment surface
Gas molecules	Hover discs

How to proceed:

After aligning the air-cushion table horizontally, attach the magnetic barriers at the edges of the experiment surface. The experiment surface is divided in half by placing the manipulating rod onto the middle of barriers nos. 3 and 4. Spread the discs anywhere across the experiment surface and turn the fan to a medium setting.

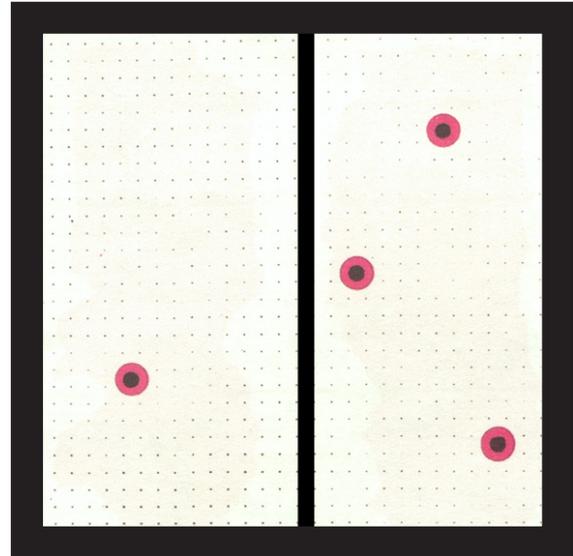
Increase the motion of the hover discs to a high mean velocity by repeatedly opening the impulse valve for a short time. When a specified period of time has elapsed, examine the distribution of the 4 hover discs in both spaces. This is done by covering the connector opening of the fan with the hand. Record the calculated distribution in table 1. Then release the opening again and open the impulse valve several times. Cover the opening again after the specified period of time, record the distribution, etc.

Depict the relative frequency of each possible distribution in a bar chart after 20 experiments, 40 experiments, etc. (Fig. 5)

Result:

Although the hover discs move in a completely disorderly fashion, the result obtained from a large number of experiments is that the distribution across both halves is subject to certain rules. The distribution occurring most frequently is 2:2, followed by the 3:1 and 1:3 distributions

and finally, considerably less often, the 4:0 and 0:4 distributions. The frequencies of the 3:1 and 1:3 distributions are approximately equal, as are the 4:0 and 0:4 distributions.



Interpretation:

The distribution of the molecules in a gas is governed by the laws of statistics. In the case of 4 molecules distributed onto 2 half spaces, the 0:4, 1:3, 2:2, 3:1 and 4:0 distributions occur at a ratio of 1 : 4 : 6 : 4 : 1. This corresponds to the relative frequencies of 6.25 % : 25 % : 37.5 % : 25% : 6.25%.

Note:

An easier method to determine the individual distributions is to calculate and record the distribution after a specified period of time (e.g. 5 seconds). It is sufficient to observe only one half of the experiment surface and to determine how many hover discs it contains at the specified points in time.

The number of hover discs contained in the other half is obtained by deduction from 4.

The ratio of distributions given above is applicable under the assumption that the molecules have a very low volume and that the repulsive forces are effective only in the immediate proximity of the molecules. These conditions are not given in the case of the hover discs used for demonstration. This is why the 2:2 distribution is overrepresented in the experiment, while the other distributions occur less often than expected.

Table 1					
Distribution	0 : 4	1 : 3	2 : 2	3 : 1	4 : 0
Relative frequency in %	5	20	49	21	5

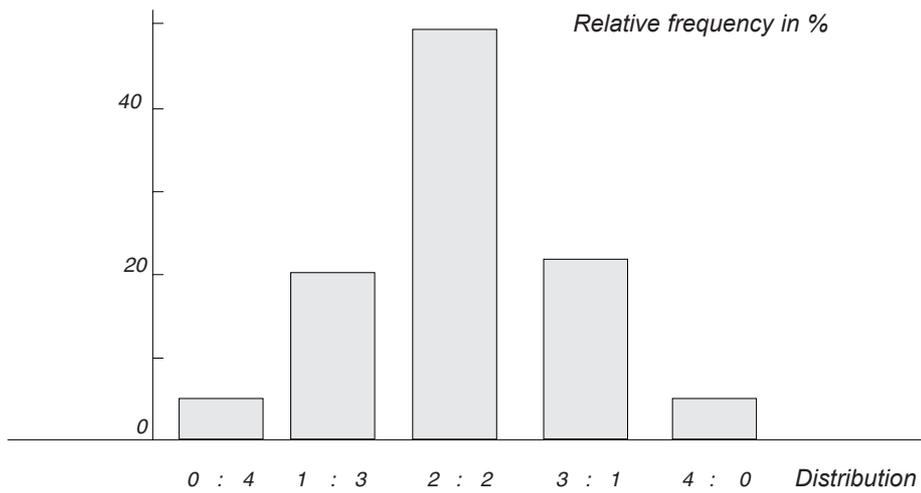


Fig. 5: Relative frequency of the distributions in 100 experiments

2.2 Structure and Properties of the Liquids

2.2.1 Configuration and Motion of Molecules in a Liquid

Components:

Air-cushion table with fan	
Overhead projector	
Magnetic barrier, long	2 Pieces
Magnetic barrier, short	2 Pieces
Hover disc, orange	25 Pieces

Model simulation	
Real Object	Model
Vessel containing the liquid	Experiment surface of the air-cushion table
Walls of the vessel	Magnetic barriers
Molecules of the liquid	Hover discs

How to proceed:

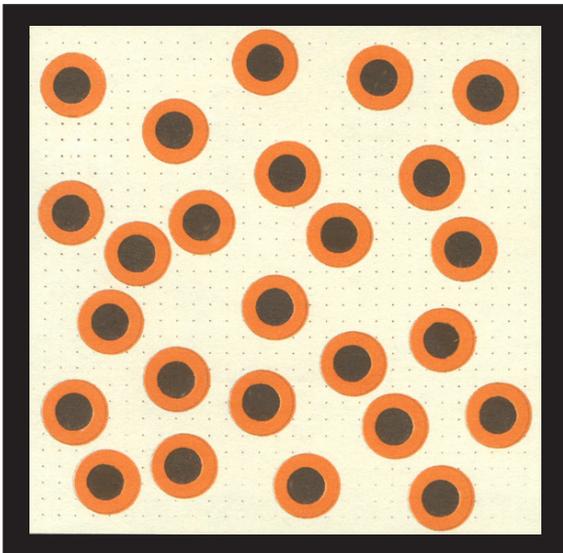
Align the air-cushion table horizontally. First place the magnetic barriers on the experiment surface and next the hover discs.

Turn the fan to a setting in which the hover discs are sure to float even when the impulse valve is opened. Briefly open the impulse valve several times so that the mean velocity of the discs is as high as possible.

Observe the arrangement and motion of the hover discs.

Result:

The hover discs are irregularly arranged at short distances. Each hover disc performs oscillating and circular motions around its location. However, it is not bound to any specific location, rather changing it at irregular intervals or moving



on between the other discs.

The kinetic energy differs from disc to disc and changes from time to time in each disc.

The hover discs are irregularly arranged at short distances. Each hover disc performs oscillating and circular motions around its location. However, it is not bound to any specific location, rather changing it at irregular intervals or moving on between the other discs.

The kinetic energy differs from disc to disc and changes from time to time in each disc.

Interpretation:

The molecules of a liquid are in permanent, irregular motion, with prevailing oscillating and circular motions around the respective location. In almost every molecule these motions are temporarily superimposed by irregular translational movements. The kinetic energy of the individual molecules varies and is constantly changing.

2.2.2 Increase of Temperature in Liquids when Supplying Energy

Components:

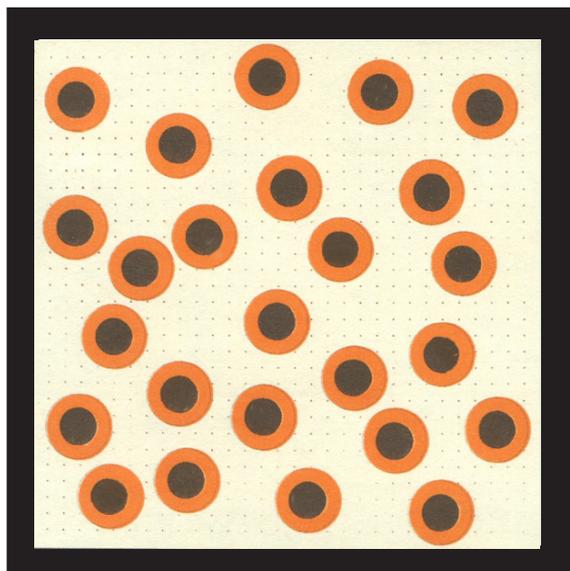
Air-cushion table with fan	
Overhead projector	
Magnetic barrier, long	2 Pieces
Magnetic barrier, short	2 Pieces
Hover disc, orange	25 Pieces

Model simulation	
Real Object	Model
Vessel containing the liquid	Experiment surface of the air-cushion table
Walls of the vessel	Magnetic barriers
Molecules of the liquid	Hover discs

How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers. Place the hover discs on the experiment surface.

Turn the fan to setting in which the hover discs are sure to lift off. Initially, the velocity of the hover discs has to be kept low by briefly opening the impulse valve at rather long intervals. Gradually increase the velocity by opening the valve at shorter intervals. Observe the motion of the hover discs.



Result:

As an increased amount of energy is supplied, the motion of the hover discs becomes stronger. They perform their oscillating motions at higher amplitudes, exchange their locations more frequently and move from one place to another at higher speed.

Interpretation:

When supplying energy to a liquid, the mean kinetic energy of the molecules increases. The temperature rises.

2.2.3 Diffusion von Flüssigkeiten

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Hover disc, red 20 Pieces
- Hover disc, green 20 Pieces

Model simulation	
Real Object	Model
Vessel containing the liquid	Experiment surface of the air-cushion table
Walls of the vessel	Magnetic barriers
Molecules of one liquid	Red hover discs
Molecules of the other liquid	Green hover discs

How to proceed:

Align the air-cushion table horizontally and place the magnetic barriers on the experiment surface. Spread the hover discs evenly across the entire experiment surface so that all green discs are arranged in one half and all red ones in the other half and the line dividing them runs parallel to barriers nos. 1 and 2.

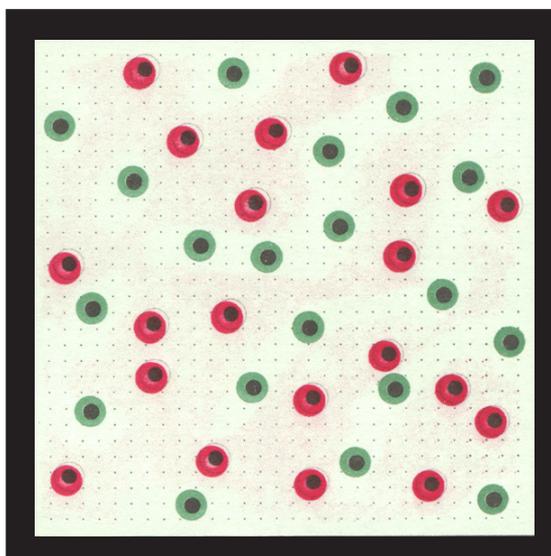
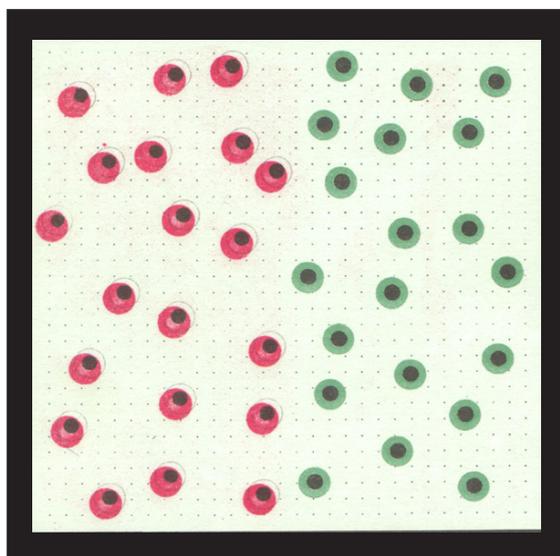
Turn the fan to a setting in which the hover discs are sure to float even when opening the impulse valve. Observe the motions of the hover discs, especially in the area around the borderline.

Result:

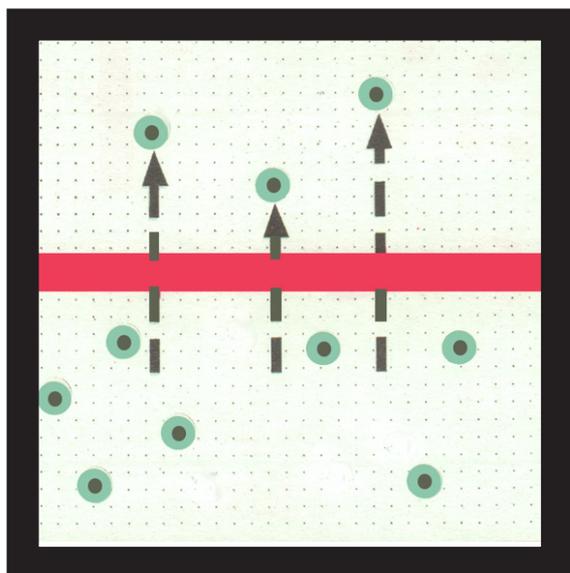
The hover discs gradually mix in the area of the borderline as a result of the occasional translational motions. With time, more and more red discs move into the area of the green ones and vice versa. After some time, the discs have mixed completely.

Interpretation:

The disordered motions of the molecules causes the liquids to mix by themselves. Due to the low translation speed the diffusion in liquids occurs much slower than in gases.



The larger the mean velocity of the hover discs is, the faster individual discs will leave the original section.



Interpretation:

A liquid contains molecules of different velocities at all times. The fastest among these molecules succeed in leaving the liquid. This process of evaporation also occurs beneath the boiling temperature of the liquid. Since molecules from the gas atmosphere also return into the liquid, a dynamic equilibrium state is soon reached. The speed of evaporation increases as the temperature rises.

Note:

The inclination of the experiment surface simulates the gravitational field. This makes more particles return from the gas phase into the liquid phase.

2.2.6 Liquefaction of a Gas through Pressure

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Magnetic piston 1 Piece
- Guide piece for the magnetic piston 1 Piece
- Hover disc, red 20 Pieces

Model simulation	
Real Object	Model
Vessel containing the liquid	Experiment surface of the air-cushion table
Walls of the vessel	Magnetic barriers
Piston for the compression of the gas	Magnetic piston
Gas molecules	Hover discs

How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers. Place the piston on the experiment surface right next to barrier no. 2. The guide piece for the magnetic piston placed onto magnetic barrier no. 2 ensures excellent guidance of the piston rod. Arrange the magnetic hover discs near barrier no.1.

Turn the fan to a medium setting. Slowly move the piston towards barrier no.1 until the available area for the hover discs is less than half of the experiment surface. Observe the configuration and motions of the hover discs.

Result:

Reducing the area in size changes the behavior of the hover discs. The number of impacts increases. The distances in which the hover discs can move in a straight line become shorter and shorter. Oscillating and circular motions prevail. Permanent changes in location mostly occur as a mutual exchange of positions.

Interpretation:

Under certain conditions, the compression of a gas can result in liquefaction. The configuration of the molecules and their type of motion change in this process. While in the gaseous aggregation state only translational movements occur, the motion prevailing in the liquid state is oscillation around the respective location.

2.2.7 Solidification of a Liquid

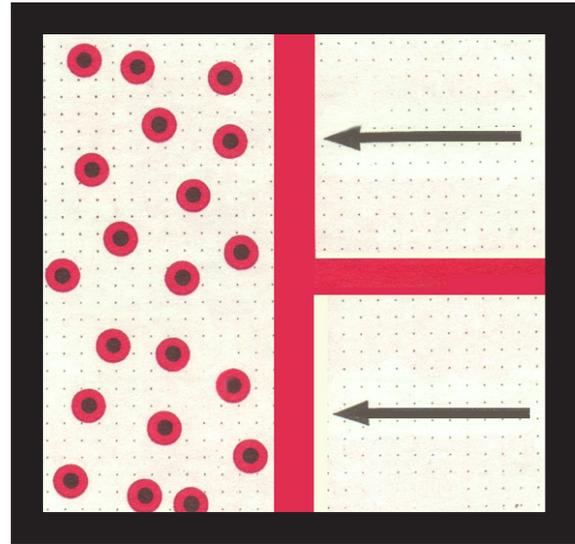
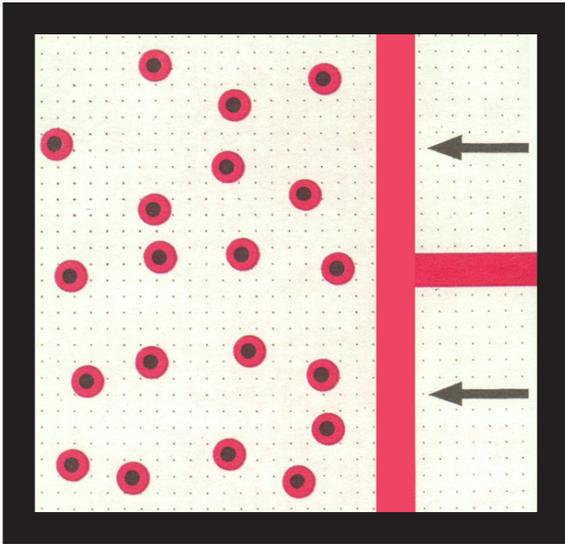
Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Hover disc, orange 25 Pieces

Model simulation	
Real Object	Model
Vessel containing the liquid	Experiment surface of the air-cushion table
Walls of the vessel	Magnetic barriers
Molecules of the liquid	Hover discs

How to proceed:

Align the air-cushion table horizontally and attach



the magnetic barriers. Spread the hover discs evenly across the experiment surface.

Adjust the airflow strong enough to ensure that the hover discs lift off even when the impulse valve is opened. Briefly open the impulse valve several times so that the hover discs have a high mean kinetic energy. Observe the motions of the hover discs.

Result:

At first, the hover discs perform oscillating and circular motions superimposed on their translational movements. Their mean kinetic energy gradually drops. The amplitudes of the oscillations decrease, translational movements occur less often. After a while there still are

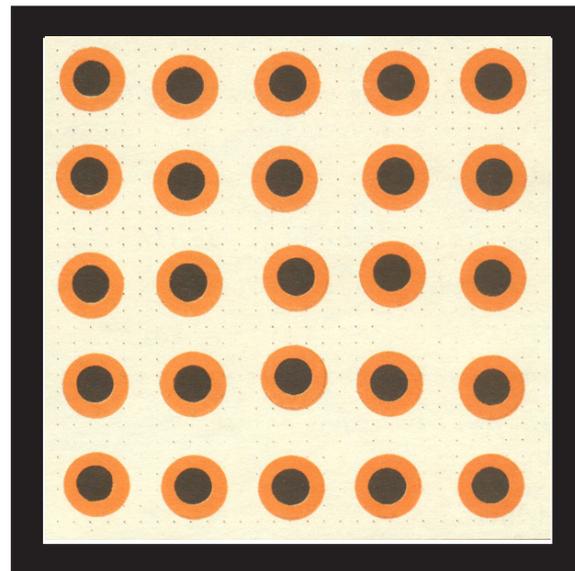
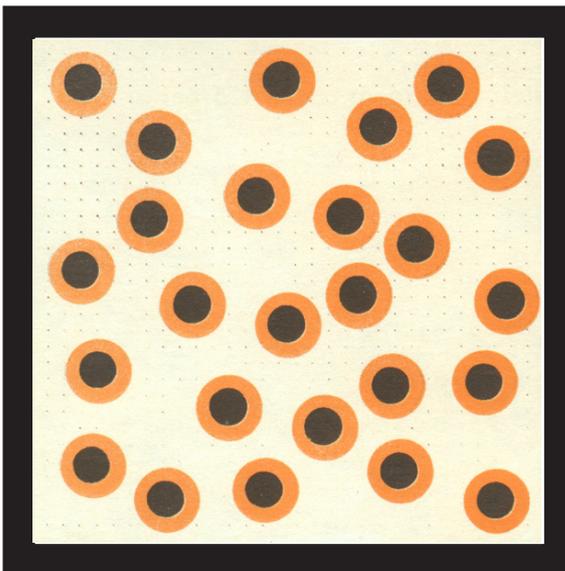
occasional exchanges of position. Finally, each hover disc only moves around its own equilibrium position.

Interpretation:

Reducing the temperature of a liquid leads to its solidification. The drop in temperature causes a drop in the mean kinetic energy of the molecules of the liquid. In the process of solidification, each molecule occupies a specific location, around which it performs irregular oscillating motions.

Note:

The mean velocity of the hover discs will drop faster when the fan is turned to a lower setting.



2.3 Structure and Properties of Solids

2.3.1 Configuration and Motions of the Lattice Elements in a Solid

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Hover disc, orange 25 Pieces

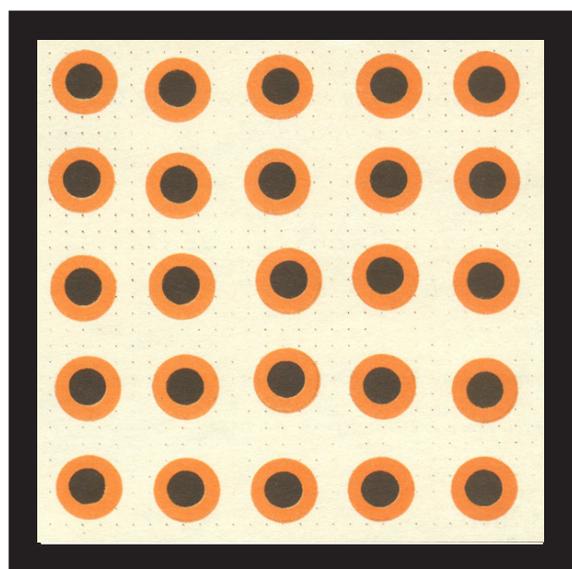
Model simulation	
Real object	Model
Space in which the behavior of the solid is observed	Experiment surface of the air-cushion table
Adjacent lattice elements	Magnetic barriers
Lattice elements of the solid	Hover discs

How to proceed:

Align the air-cushion table horizontally, attach the magnetic barriers and spread the hover discs evenly across the experiment surface. Adjust the airflow strong enough so that the hover discs are sure to float even when the impulse valve is opened. Observe the motion of the hover discs after opening the impulse valve once.

Result:

Each hover disc is bound to a specific location. It performs oscillating and circular motions around its equilibrium position. The amplitudes vary and are constantly changing. The mean kinetic energy of the hover discs gradually decreases.



Interpretation:

The lattice elements in a solid are arranged in a regular configuration. They perform irregular oscillations around their equilibrium position. The amplitudes vary from location to location and change with time. A drop in temperature makes the mean kinetic energy of the oscillating lattice elements decrease.

Note:

To provide a proper demonstration of the drop in temperature it is recommended to turn the fan down as far as possible during the experiment. This experiment can also be demonstrated using red or green discs. It will be necessary, however, to reduce the effective experiment surface by shifting barrier no. 2 to the middle of the air-cushion table.

2.3.2 Melting a Solid

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Hover disc, orange 25 Pieces

Model simulation	
Real object	Model
Space in which the behavior of the solid is observed	Experiment surface of the air-cushion table
Adjacent lattice elements	Magnetic barriers
Lattice elements of the solid	Hover discs

How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers. Spread the hover discs evenly across the experiment surface. Adjust the airflow strong enough so that all hover discs are sure to float even when the impulse valve is opened. Open the impulse valve several times at an interval of several seconds and observe the motion of the hover discs.

2.4. Processes of Electric Conduction

2.4.1 Motion of an Electron in a Vacuum Under the Influence of an Electric Field (Demonstrated By Means of Mechanical Forces)

Components:

Air-cushion table with fan	
Overhead projector	
Magnetic barrier, short	1 Piece
Hover disc, orange	1 Piece

Model simulation	
Real Object	Model
Space containing an electric field	Experiment surface of the air-cushion table
Strength of the electric field	Inclination of the experiment surface
Electron	Hover disc

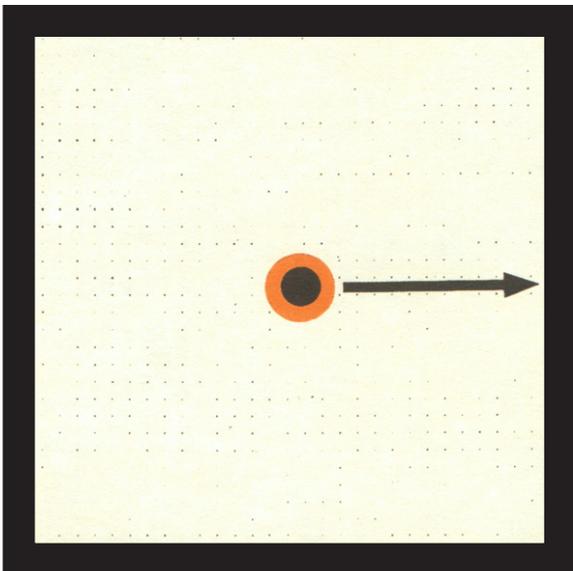
How to proceed:

Align the air-cushion table horizontally. Attach magnetic barrier no. 2 in a reversed position with the number facing downwards, in order to hold the hover disc. Use the adjusting screw at barrier no. 2 to lower the experiment surface on that side, selecting a slight inclination.

Turn the fan to a medium setting. Place the hover disc on the opposite side of the experiment surface, holding it with the finger. Then release it and observe its motion. Repeat the experiment selecting a stronger inclination of the experiment surface.

Result:

The motion of the hover disc accelerates. The acceleration increases with the degree of inclination.



Interpretation:

The motion of electrons in an electric field is accelerated, provided that no other forces act on the electrons. The acceleration increases with the intensity of the electric field.

2.4.2 Deflection of an Electron Radiation in the Electric Field

Components:

Air-cushion table with fan	
Overhead projector	
Magnetic barrier, short	1 Piece
Electrode	2 Pieces
Manipulating rod	1 Piece
Hover disc, green	2 Pieces
Aluminum hover disc	5 Pieces
High-voltage source	

Model simulation	
Real Object	Model
Vacuum containing an electric field	Experiment surface of the air-cushion table
Electrodes	Electrodes
Electrons	Aluminum hover discs

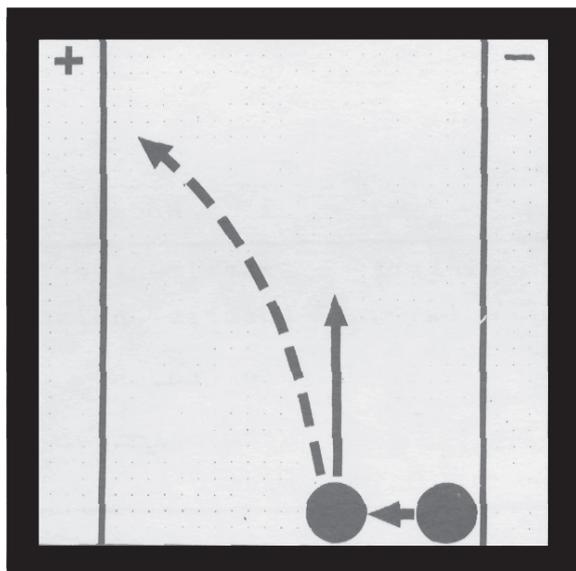
How to proceed:

Carefully align the air-cushion table in a horizontal position using the spirit levels. Place the electrodes onto the experiment surface parallel to sides nos. 1 and 2, so that the electrode on side no. 2 rests on its bases, while the bases of the other electrode point upwards. Position barrier no. 2 outside of the experiment surface on side no. 2, running parallel to the electrode on side no. 2. It is turned by 180° so that the hover discs cling to it because of the magnetic attraction.

Arrange 2 green hover discs closely to each other on side no. 3. They are meant to give the aluminum disc a certain initial velocity. Feed the direct current of the high-voltage source to the electrodes. Use the manipulating rod to move an aluminum disc towards the electrode on side no. 1, so that it is charged. Then move it to the edge of the experiment surface on side no. 3, between the two green discs. Turn the fan to a medium setting and observe the motion of the hover disc. Repeat the experiment with the other aluminum discs, varying the distance of the green discs from the experiment surface.

Result:

The hover discs move towards the opposite electrode on a parabolic path.



Interpretation:

Electrons are subject to a force in the electric field. When the electrons in a vacuum enter an electric field at a perpendicular angle to the field lines, they are forced onto parabolic paths. Their velocity increases in this process.

Note:

It is recommended to conduct this experiment without an electric field at first, in order to demonstrate the straight, uniform movement of the electrons.

2.4.3 Motion of Electrons in a Vacuum Under the Influence of an Electric Field

Components:

- Air-cushion table with fan
- Overhead projector
- Electrode 2 Pieces
- Magnetic barrier, short 1 Piece
- Aluminum hover disc 5 Pieces
- Plastic tweezers 1 Piece
- High-voltage source

Model simulation	
<i>Real Object</i>	<i>Model</i>
Vacuum containing an electric field	Experiment surface of the air-cushion table
Electrodes	Electrodes
Electrons	Hover discs made of aluminum

How to proceed:

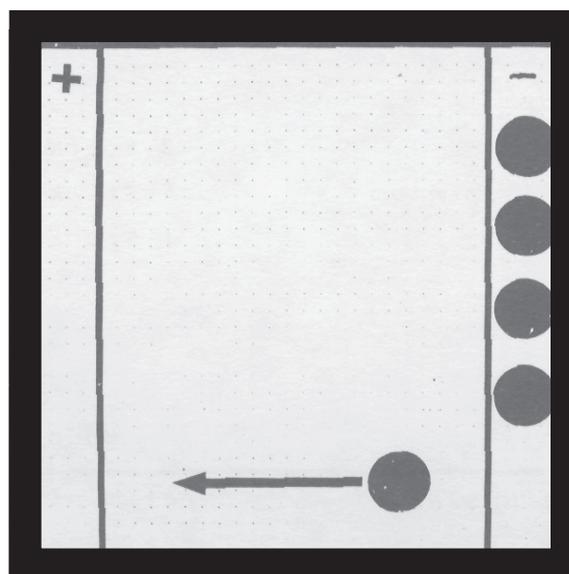
Carefully align the air-cushion table in a hori-

zontal position using the spirit levels. Arrange the electrodes at the edges of the experiment surface parallel to each other. The electrode on side no. 2 is set on its bases, whereas the bases of the other electrode point upwards. Place the magnetic barrier, turned by 180°, closely to the experiment surface parallel to the electrode on side no. 2, so that the hover discs cling to it due to the magnetic attraction. Connect the electrodes to the high-voltage source in such way that the anode is located next to the magnetic barrier. Then place the hover discs onto the cathode.

Feed d.c. voltage to the electrodes and turn the fan to a medium setting. Then lift the hover discs off the cathode using the tweezers and place them onto the experiment surface one by one, positioning them directly in front of the cathode. Observe their motions between the electrodes.

Result:

The hover discs move from one electrode to the other in an accelerated way.



Interpretation:

The electrons in a vacuum will move in an accelerated way from the cathode to the anode under the influence of an electric field.

2.4.4 Principle of Electric Conduction

Components:

- Air-cushion table with fan
- Overhead projector
- Electrode 2 Pieces
- Hover disc made of aluminum 5 Pieces
- Plastic tweezers 1 Piece
- High-voltage source

Model simulation	
Real Object	Model
Space containing an electric field	Experiment surface of the air-cushion table
Electrodes	Electrodes
Charge carriers	Aluminum hover discs

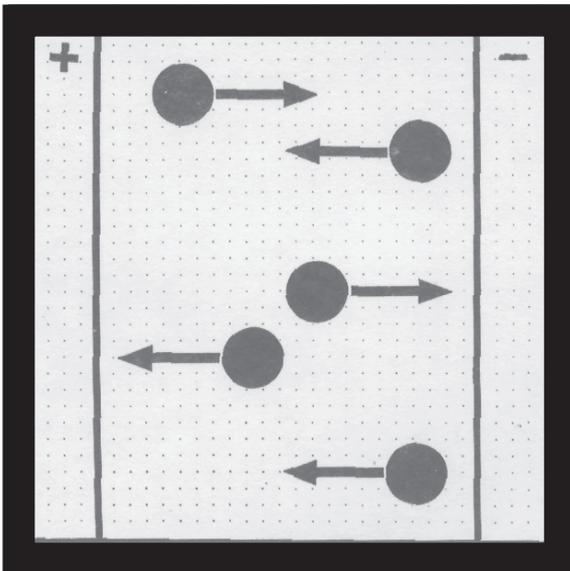
How to proceed:

Align the air-cushion table horizontally. Arrange the two electrodes on two sides opposite each other, so that they rest directly on the experiment surface with their bases pointing upwards. Connect them to the high-voltage source. Place a hover disc directly next to an electrode.

Feed d.c. voltage to the electrodes. Turn the fan to a setting in which the hover disc is sure to lift off. Then place the remaining discs onto the experiment surface one after the other, using the tweezers and placing them directly next to an electrode. Observe the motions of the hover discs.

Result:

The hover discs move back and forth between the electrodes under the influence of the electric field.



Interpretation:

When slightly moving particles (charge carriers) are located in an electric field, they will pick up charges at one electrode and transport them to the opposing one. There they will discharge these and pick up charges of the opposite polarity. Then they will return to the first electrode, etc. This directed movement of the charge carriers represents a current.

Notes:

This experiment offers a clear demonstration of the conditions existing for example when grains or aluminum flakes move back and forth between the plates of a plate capacitor through the influence of the electric field.

This setup is also suited to simulate the process of conduction with bipolar charge carriers. To do this, place an approx. 8-cm wide cardboard strip on each electrode. It should protrude from the electrodes approx. 3 cm into the space between the electrodes. When repeating the experiment under these conditions, the charge carrier seems to disappear in the respective electrode. Later it will leave the electrode as a “different” charge carrier (of the opposite polarity).

2.4.5 Influence of Lattice Elements on the Motions of Electrons in an Electric Field

Components:

- Air-cushion table with fan
- Overhead projector
- Holding device
- Plexiglas plate
- Electrode 2 Pieces
- Manipulating rod 1 Piece
- Hover disc, orange 1 Piece
- Hover disc made of aluminum 4 Pieces
- High-voltage source

Model simulation	
Real Object	Model
Part of a metallic conductor	Experiment surface of the air-cushion table
Lattice element of the metal	Orange disc
Electrodes	Electrodes
Conduction electrons	Aluminum hover discs

How to proceed:

Align the air-cushion table horizontally. Arrange the two electrodes on two opposing sides of the experiment surface, so that they rest directly on its surface with their bases pointing upwards. Attach the holding device to the air-cushion table and insert the Plexiglas plate. Place the four aluminum discs on the experiment surface and shift them towards one of the electrodes. Connect the electrodes to the high-voltage source.

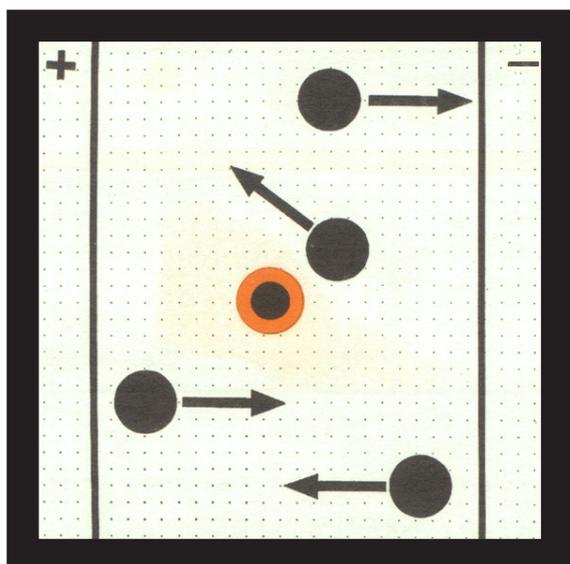
Feed d.c. voltage to the electrodes. Turn up the fan so that all hover discs lift off. Observe their

motions. Then place the orange disc onto the Plexiglas plate above the center of the experiment surface. Its magnet should face downwards so that the aluminum discs are repelled. Set the Plexiglas plate to different heights to vary the influence of the orange disc on the aluminum ones. Observe their motions.

Result:

At first, the hover discs move from one electrode to the other and back. With the exception of few mutual interferences, these motions are mostly straight.

The influence of the orange disc is a major impediment to these motions. The aluminum discs can often only succeed in reaching the opposite side after taking major detours. The lower the Plexiglas plate is set, the stronger the interference by the orange disc will be.



Interpretation:

Conduction electrons move practically unimpeded between the lattice elements of a metal. However, near the lattice element there is strong interference.

Notes:

The fact that the directed movement of the electrons only occurs from the cathode to the anode is neglected intentionally.

2.4.6 Motion of an Electron in a Metal Lattice Under the Influence of the Electric Field – Ohmic Resistance (Demonstrated By Means of Mechanical Forces)

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, short 1 Piece
- Holding device 1 Piece
- Lattice model 1 Piece
- Manipulating rod 1 Piece
- Hover disc, orange 1 Piece

Model simulation	
<i>Real Object</i>	<i>Model</i>
Part of a metallic conductor	Experiment surface of the air-cushion table
Metal lattice	Lattice model
Strength of the electric field	Inclination of the experiment surface
Electron	Hover disc

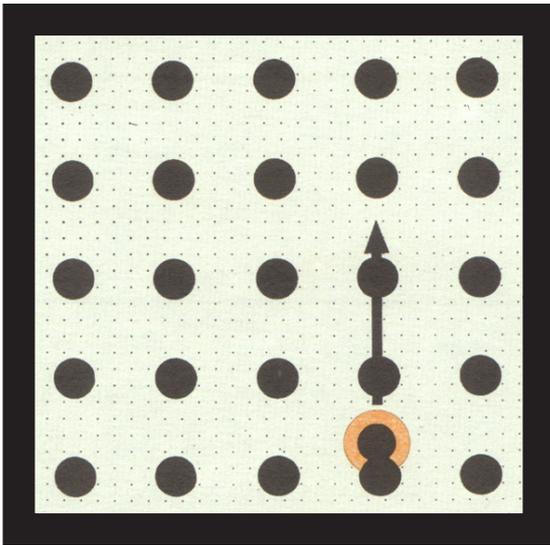
How to proceed:

Align the air-cushion table horizontally. Turn magnetic barrier no. 2 by 180° and place it onto its position on the experiment surface. Attach the holding device to the air-cushion table and insert the lattice model. Slide it along the groove of the holding device until its edge at barrier no. 2 is positioned above the last row of holes in the air jet plate. This is to produce an approx. 3-cm wide strip between the lattice model and the pressure chamber through which the hover discs can be placed onto the experiment surface. Set the lattice model to the lowest position. Use the adjusting screw at barrier no. 2 to select a slight inclination of the table by lowering the table part at this side. Place the hover disc onto the experiment surface next to the pressure chamber. Turn up the fan to make the hover disc float. Observe its motions and those of the hanging magnets. Repeat the experiment selecting different degrees of inclination for the experiment surface.

Result:

The lattice model influences the motions of the

hover disc in such way that the mean drift velocity is constant. The hover disc is slowed down by the interactions with the oscillating magnets. It transfers part of its energy to the magnets so that the amplitude of their oscillations increases. Both the velocity of the hover disc and the amplitude of the lattice oscillations increase as the degree of inclination of the air-cushion table is increased



Interpretation:

The electrons in a metallic conductor move at a constant mean velocity under the influence of an electric field. In the course of interacting with the lattice elements they transfer part of their energy onto these, causing an increase in the lattice oscillations and therefore also a rise in the temperature of the conductor.

2.4.7 Motion of the Free Electrons in a Metal

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Holding device 1 Piece
- Lattice model 1 Piece
- Hover disc, red 25 Pieces

Model simulation	
Real Object	Model
Part of a metallic conductor	Experiment surface of the air-cushion table
Metal lattice	Lattice model
Electrons	Hover discs

How to proceed:

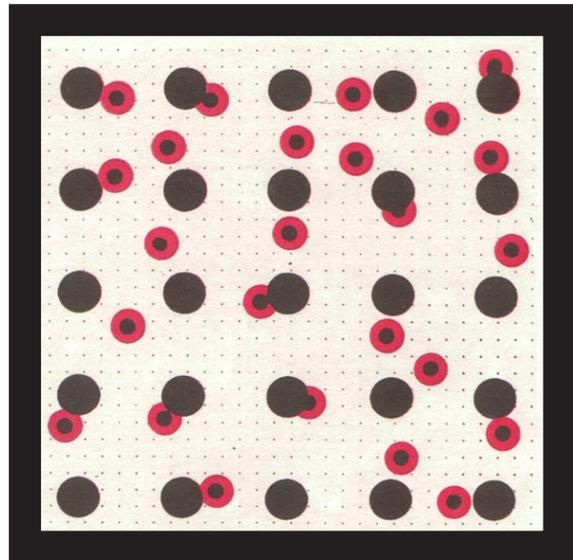
Align the air-cushion table horizontally and ar-

range the magnetic barriers around the experiment surface. Attach the holding device to the air-cushion table and insert the lattice model. Set it to its highest position. Place the hover discs onto the experiment surface.

Turn up the fan so that all hover discs move freely on the air-cushion table. Observe their motions and interactions with the magnets of the lattice model.

Result:

The motions of the hover discs are similar to those of the molecules of a gas. Interactions occur when they approach a magnet of the lattice model. A hover disc with a high velocity can make a hanging magnet oscillate at a higher amplitude. A hanging magnet with higher oscillations can cause the velocity of a hover disc to rise.



Interpretation:

The motions of conduction electrons in a metal are similar to the motions of the molecules in a gas. They interact with the lattice elements. A rise in the temperature of the metal causes an increase in the mean velocity of the electrons. An increased velocity of the electrons causes a rise in the temperature of the metal.

2.4.8 Thermal Emission

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Holding device 1 Piece
- Lattice model 1 Piece
- Hover disc, red 15 Pieces
- Hover disc, green 11 Pieces

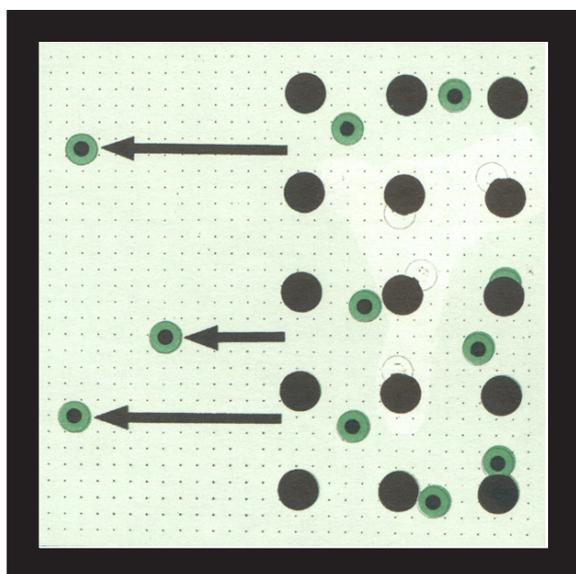
Model simulation	
Real Object	Model
Part of a metal	Part of the experiment surface under the dynamic lattice
Vacuum	Part of the experiment surface not situated under the dynamic lattice
Metal lattice	Lattice model
Electrons	Hover discs

How to proceed:

Align the air-cushion table horizontally and arrange the magnetic barriers. Attach the holding device and insert the lattice model. Set it to a medium height. Slide it outwards in the groove until 2 rows of the hanging magnets are located above the impulse valve. Attach one red disc to each hanging magnet of the remaining 3 rows. These cling to the magnets due to the magnetic attraction. Place the green discs on the experiment surface and slide them under the lattice model. Turn up the fan to a setting in which all discs are sure to lift off. Briefly open the impulse valve several times to increase the mean velocity of the hover discs and the amplitude of the hanging magnets. Observe the behavior of the hover discs.

Result:

Some of the hover discs overcome the forces of the lattice magnets and return to the vacant area of the air-cushion table. Some discs return to the space underneath the lattice model. The stronger the motions of the hover discs or lattice magnets, the more hover discs escape the space under the lattice model.



Interpretation:

To enable the electrons to escape the surface, they have to possess a specific minimum energy. This corresponds to the work of escape. Some of the electrons possess this kinetic energy at high temperatures of the metal. The higher this temperature is, the more electrons can escape it in a specific period of time.

2.4.9 Bound Charge Carriers in an Insulator

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Holding device 1 Piece
- Lattice model 1 Piece
- Manipulating rod 1 Piece
- Hover disc, red 25 Pieces

Model simulation	
Real Object	Model
Part of an insulator	Experiment surface of the air-cushion table
Crystal lattice of the insulator	Lattice model
Strength of the electric field	Inclination of the experiment surface
Electrons	Hover discs

How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers. Spread the 25 hover discs evenly across the experiment surface. Then attach the holding device and insert the lattice model. Set it to the lowest possible height, taking care, however, that the hover discs are not attracted by the hanging magnets. Turn the fan to a setting in which all hover discs lift off. Observe their motions and interactions with the lattice model. Then gradually increase the degree of inclination of the experiment surface and observe the behavior of the hover discs.

Result:

All hover discs are tightly bound to their location and oscillate around their equilibrium position at low amplitudes. Even when the experiment surface is inclined to a higher degree, they will not escape their positions.

Model simulation	
Real Object	Model
Part of a semiconductor	Experiment surface of the air-cushion table
Crystal lattice of the semiconductor	Lattice model
Positive ions of the crystal lattice	Lattice magnets
Electrons	Hover discs

How to proceed:

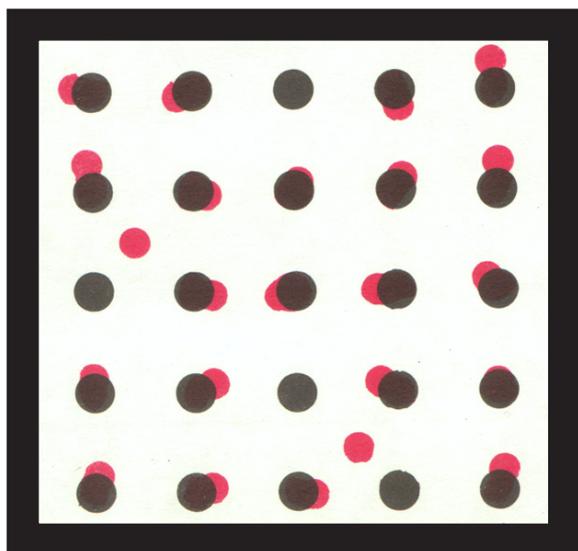
Align the air-cushion table horizontally and attach the magnetic barriers. Spread the discs evenly across the experiment surface. Attach the holding device to the air-cushion table and insert the lattice model. Set it to a medium height.

Turn the fan to a setting in which all discs are sure to lift off. If necessary, use the manipulating rod to ensure that there is a disc under each hanging magnet. Repeatedly open the impulse valve to increase the velocity of the hover discs. Observe their configuration and motions.

Finally, gradually increase the degree of inclination of the table using the adjusting screw at barrier no. 2 and observe the influence of the degree of inclination on the hover discs.

Result:

At low velocities, all hover discs are positioned under the magnets of the lattice model. At higher velocities, some of the hover discs leave their positions. The effect of inclining the experiment surface is that the disordered motions of the hover discs receive a preferential direction.



Interpretation:

In an intrinsic semiconductor, some electrons are released from the lattice under the influence of a

rise in temperature, so that they move throughout the semiconductor. The released electrons leave behind positive “holes”. The number of migrating electrons and the number of holes are equal. Feeding voltage causes an electric current to flow. The preferential motion of the electrons is towards the positive electrode, that of the “holes”, as it seems, in the opposite direction.

2.4.12 Electric Conduction in a Semiconductor – N-Type Conduction (Demonstrated By Means of Mechanical Forces)

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Holding device 1 Piece
- Lattice model 1 Piece
- Manipulating rod 1 Piece
- Hover disc, red 28 Pieces

Model simulation	
Real Object	Model
Part of a semiconductor	Experiment surface of the air-cushion table
Crystal lattice of the semiconductor	Lattice model
Positive ions of the crystal lattice	Lattice magnets
Electrons	Hover discs
Strength of the electric field	Inclination of the experiment surface

How to proceed:

Align the air-cushion table horizontally and attach the magnetic barriers around the experiment surface. Spread the discs evenly across the experiment surface. Attach the holding device and insert the lattice model. Set it to a medium height. Turn the fan to a setting in which all hover discs float freely. Observe the configuration and motions of the hover discs. Then tilt the experiment surface of the air-cushion table.

Open the impulse valve several times and repeat the experiment at an increased velocity of the hover discs.

Result:

At the lower velocity, 25 hover discs are bound rather closely to the magnets of the lattice model. The other three move in the gaps between them in disorderly fashion. The effect of inclining the

2.5 Nuclear Physics

2.5.1 Scattering of Positively Charged Particles Near an Atomic Nucleus

Components:

- Air-cushion table with fan
- Overhead projector
- Holding device
- Plexiglas plate
- Hover disc, orange 5 Pieces

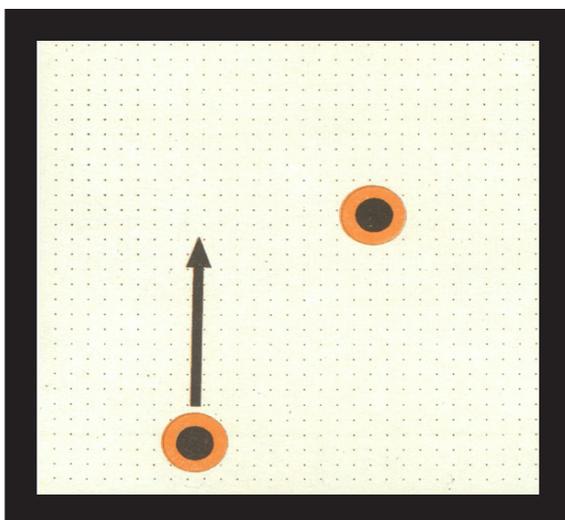
Model simulation:	
<i>Real Object</i>	<i>Model</i>
Space in which the positively charged particles move	Experiment surface of the air-cushion table
Atomic nucleus	Stacked hover discs
Positively charged particle	Hover disc

How to proceed:

Carefully align the air-cushion table to a horizontal setting using the spirit levels. Attach the holding device to the air-cushion device and insert the Plexiglas plate.

Place the 4 stacked discs in the middle of the Plexiglas plate with their magnets facing downwards. This is to ensure repulsion of the hover disc on the experiment surface. Set this disc into motion at the lowest possible velocity from the edge of the experiment surface towards the stacked magnets.

Repeat this experiment at various speeds. Then vary the direction of motion, making the hover disc float along the stacked magnets at gradually increasing distances from experiment to experiment.



Result:

The hover disc changes its direction of motion near the stacked magnets. This change in the direction of motion is stronger the lower the velocity of the hover disc is and the closer the path runs along the stacked discs.

Interpretation:

Charged particles are scattered near the atomic nucleus. The scattering angle depends on the velocity and the initial direction of the particles.

2.5.2 Scattering of Alpha Particles When Passing Through a Metal Foil

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Magnetic barrier consisting of 4 magnets 1 Piece
- Hover disc, red 1 Piece

Model simulation:	
<i>Real Object</i>	<i>Model</i>
Space in which the alpha particles move	Experiment surface of the air-cushion table
Metal foil	Magnetic barrier made of 4 magnets
Atomic nuclei	Ceramic magnets of the barrier
Alpha particles	Hover discs

How to proceed:

Carefully align the air-cushion table to a horizontal setting using the spirit levels. Attach the magnetic barriers, turning barrier no. 2 by 180° so that it holds the approaching hover disc. Place the ends of the magnetic barrier consisting of 4 magnets into the recesses provided in barriers no. 3 and 4 which are located near barrier no. 2.

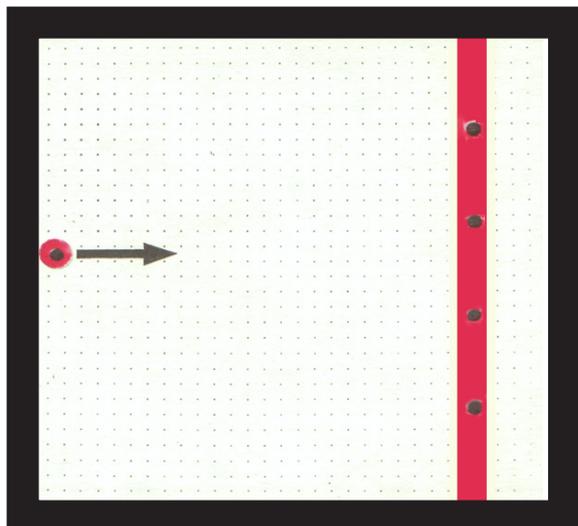
Turn the fan to a setting in which the hover disc floats freely. Move it closely to barrier no. 1. Hold it with the finger at first, then suddenly release it so that it hits the barrier of 4 magnets at high velocity.

Repeat the experiment with slight variations of the starting position. Observe the motion of the hover disc through the magnetic barrier.

Result:

In most cases, the hover disc will pass through

the magnetic barrier with the ceramic magnets without any noticeable deflection. In various cases it will change its direction of motion. It will rebound only in very rare cases.



Interpretation:

In Rutherford's scattering experiment almost all alpha particles traverse the metal foil. Only a few of them are deflected from their original direction. Strong dispersion occurs only in very rare cases.

Note:

The influence of the magnetic barrier on the motion of the hover discs can be varied by placing the barrier on the Plexiglas plate and setting the plate to the desired height. The effect of the barrier is enhanced by placing orange discs on the ceramic magnets.

2.5.3 The Rutherford Atomic Model

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Holding device 1 Piece
- Plexiglas plate 1 Piece
- Manipulating rod 1 Piece
- Hover disc, orange 1 Piece
- Hover disc, red 1 Piece

Model simulation:	
Real Object	Model
Atom	Experiment surface of the air-cushion table
Atomic nucleus	Hover disc, orange
Electron	Hover disc, red

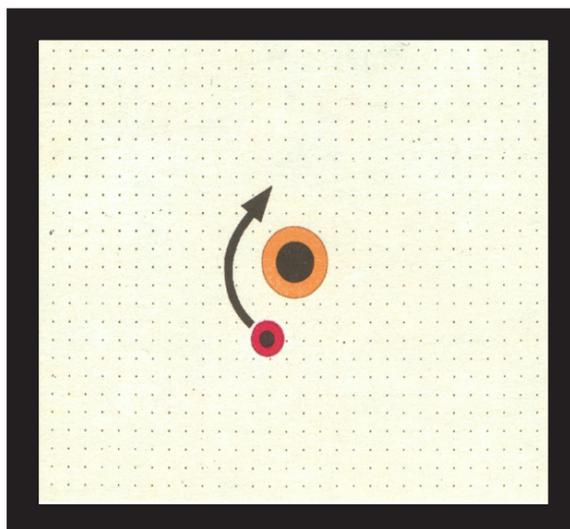
How to proceed:

Align the air-cushion table horizontally. Attach the magnetic barriers and the holding device to the air-cushion table. Insert the Plexiglas plate and position it closely above the experiment surface. Place the orange disc in the middle of the Plexiglas plate.

Turn the fan to a setting in which the red disc is sure to lift off. Use the manipulating rod to move it under the orange disc on the experiment surface. Observe its motions. Then increase its velocity by hitting it with the manipulating rod and observe it again.

Result:

The red disc moves around the orange one on varying paths. The parameters of the paths depend greatly on the speed.



Interpretation:

These experiments provide simply illustrated concept of the structure of an atom. They offer a vivid demonstration of the Rutherford atomic model, which was developed based on the results of the scattering experiments.

Note:

The experiment can be varied by stacking several orange discs and adjusting the height of the Plexiglas plate accordingly.

2.6 Mechanical Motions

2.6.1 Vertical, Horizontal and Diagonal Projection

Components:

- Air-cushion table with fan
- Overhead projector
- Hover disc, orange 2 Pieces

Model simulation:	
Real Object	Model
Space in which the projection takes place	Experiment surface of the air-cushion table
Influence of the gravitational field	Force resulting from slight inclination of the experiment surface
Projectile	Hover disc

How to proceed:

Align the air-cushion table horizontally, place the disc in the middle of the surface and turn up the fan until the disc is sure to float. Then tilt the experiment surface slightly using the adjusting screw on side no. 4. Hold the disc at the upper edge with the pointer and then release it without providing an initial motion. The projected image should clearly show the acceleration of its motion. The motion should not be too fast (by selecting an appropriate degree of inclination!). After this preliminary experiment (model experiment on the free fall), it is possible to demonstrate the various trajectories of projection. It will be necessary to select suitable starting points and an appropriate starting speed adapted to the “fall time” determined in the preliminary experiment.

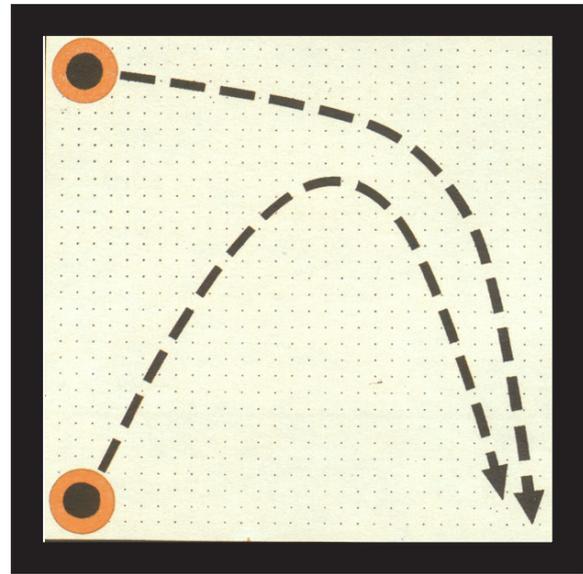
Type of projection	Starting point
vertically upwards	middle of side no. 3
horizontal	top of side no. 2
diagonal	bottom of side no. 2

Result:

The paths correspond to the flight paths in the vertical, horizontal and angular projection of an object.

Interpretation:

Since the experiment surface is tilted, uniform motions and motions with regular acceleration are superimposed, producing motions which correspond to those occurring in projections. The slight inclination of the experimenting surface causes only slight acceleration, making it possi-



able to demonstrate motions at very low speed.

2.6.2 Elastic Collision

Components:

- Air-cushion table with fan
- Overhead projector
- Magnetic barrier, long 2 Pieces
- Magnetic barrier, short 2 Pieces
- Hover disc, orange 4 Pieces

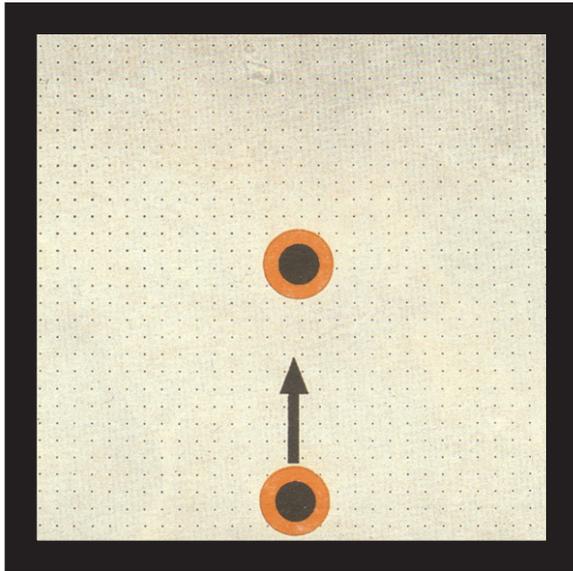
Model simulation:	
Real Object	Model
Surface on which the colliding objects move	Experiment surface of the air-cushion table
Objects participating in the elastic collision	Hover discs

How to proceed:

Carefully align the air-cushion table horizontally using the spirit levels and attach the magnetic barriers. Place two stacked hover discs in the middle of the experiment surface. Place the other doubled disc in a corner of the experiment surface, holding it with the finger and then releasing it so that it approaches the first. Repeat this process several times, with stronger or lesser deviations from a central collision. Observe the motion of both discs before and after the collision.

Result:

In case of a central collision both discs (with equal mass) exchange their velocity and therefore their kinetic energy. If the collision is not central, only part of the energy will be transferred.



Interpretation:

The air-cushion principle and utilization of the magnetic repulsive forces between ceramic magnets allow for demonstrations of fully elastic collisions.

Note:

Collisions of objects with different masses can be demonstrated by using a doubled orange disc as one collision partner and a single disc as the other.

2.6.3 Change in the Direction of Motion of an Object with a Force

Components:

- Air-cushion table with fan
- Overhead projector
- Holding device
- Plexiglas plate
- Manipulating rod
- Hover disc, orange 6 Pieces

Model simulation:	
<i>Real Object</i>	<i>Model</i>
Surface on which the object moves	Experiment surface of the air-cushion table
Object subject to a force	Orange disc
Center of force	Stacked discs

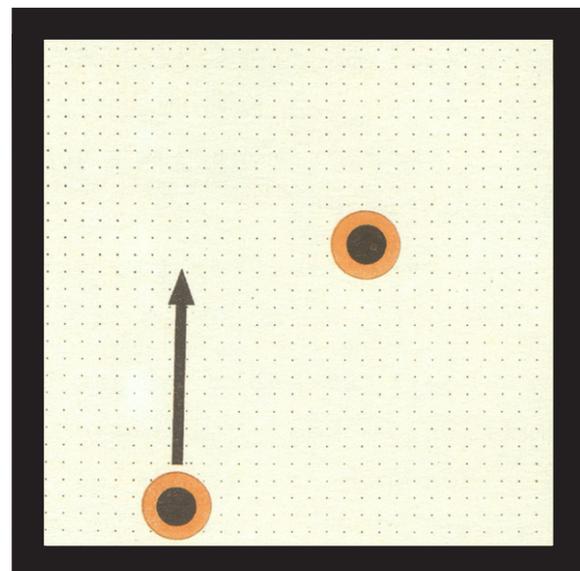
How to proceed:

Align the air-cushion table horizontally, attach the holding device and insert the Plexiglas plate. Stack four discs on the Plexiglas plate in the middle of the experiment surface.

Turn the fan to a medium setting. Set two stacked discs into slow motion starting from the edge of the experiment surface. Select a direction ensuring that it will float along the stacked discs at a distance of a few centimeters. Repeat the experiment several times, gradually reducing the shortest distance between the moving and the stacked discs. Observe the motion of the hover discs.

Result:

The hover disc will move in a straight and uniform way as long as there is no force acting on it. Its direction of movement changes near the stacked discs. The shorter the distance to the stacked discs, the stronger the change in direction.



Interpretation:

When a moving object is subjected to a force, it will be accelerated. If the direction of the force is perpendicular to the motion, the speed remains unchanged, but the direction of motion changes. The greater the force, the stronger the change in direction.

CONCLUDING REMARKS

The preceding chapters provide an overview of the setup, operating mode and possible uses of the air-cushion table. Approximately 50 experiments are described, including specific physical annotations, as well as notes on the laboratory practice of the experiments and their didactic methodology.

The following remarks are intended to complete and conclude the instructions for conducting the experiments:

- The instructions provide an overview of the main uses of the air-cushion table. The selection and configuration of the experiments used for teaching purposes shall be determined by the instructor.
- The physical interpretation of each experiment is given on a simple level, in accordance with the usually rough model illustration.
- The air-cushion table is a suitable teaching aid from the high school to the university level. The selection of the described experiments and the way of conducting them is meant to be exemplary.
- Although the air-cushion table was created for demonstration experiments, it is also suited for lab experiments, especially of the quantitative type.
- All described experiments can be demonstrated in a convincing way if they are optimized on the basis of these instructions. Following the instructions literally does not guarantee convincing effects.
- The air-cushion table is a high-quality product, which should be handled with care. Cleanliness, knowledge and skill are necessary for its successful usage.

Taking all of these remarks into consideration, the air-cushion table is highly effective teaching aid which will make a major contribution to a more profound understanding of physical phenomena , processes, terms and laws.