Electrostatics 1

Charges and Forces

– Student's work sheets

– Teacher's notes

by W. Brauers

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Contents

Introduction

The subject "Electrostatics" is dealt with in two separate books from the series "Science Teaching Modules" (STM).

This book "Electrostatics 1, Charges and Forces" is intended to stimulate the student to work independently with the equipment set ESA1 (and a few additional apparatus).

➤ Chapters 0.1/0.2 and apparatus list.

The student is familiarized with the fundamental phenomena of electrostatics in qualitative* experiments. Almost all experiments are also extremely suitable for demonstration.

It is permitted to make copies for the school's own requirements.

The experiment objectives are specified for each subject in the teacher's part.

A quick overview of the material treated can be obtained if only these parts are read in advance.

It must be remembered that the success of electrostatic experiments is a question of air humidity.

A ventilator for warm air is extremely helpful if the weather conditions are unfavorable.

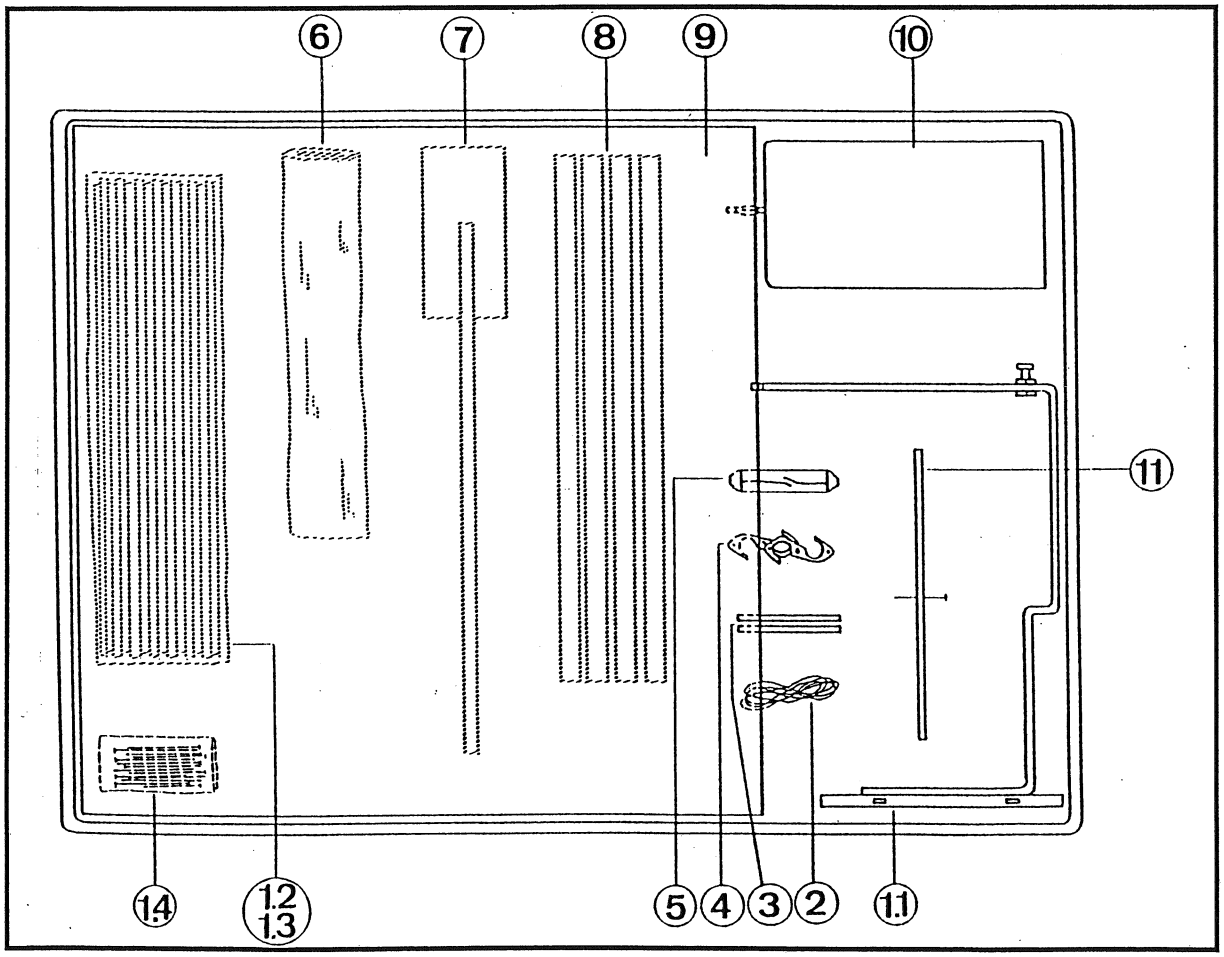
* Note:

Quantitative STM experiments on electrostatics where the electrometer amplifier (532 14) is used for measurement can be found in the book "Electrostatics 2, Charges and Fields" (589 171).

Storage and check plan for equipment set ESA 1 588 73

	1	Electroscope S, consisting of:	540 08
(1.1)		1 Electroscope base	
(1.2)		1 Metallized drinking straw	
(1.3)		50 Straws	
(1.4)		5 Needles in polyethylene bag	
(2)	1	Insulating thread, 2 m long	200 68 045
(3)	1	Electrostatic pendulum pair	200 67 941
(4)	1	Pair of plastic clips	541 06
(5)	1	Glow lamp	from 505 41
(6)	2	Polyethylene friction material	200 70 750
(7)	1	Induction plate, 40 mm x 80 mm	542 51
(8)	2	Pair of friction rods	541 00
(9)	1	Dielectric set consisting of: 1 Polystyrene sheet, 300 mm x 300 mm x 1 mm 5 Acetate transparencies, each 300 mm x 300 mm x 0.1 mm	544 25
(10)	1	Faraday cup	546 12
(11)		Empty compartment for electroscope pointer	

Fig.: ESA 1



Information on apparatus

1. Glow lamp (double-ended type) from pack with 5 each (505 41)

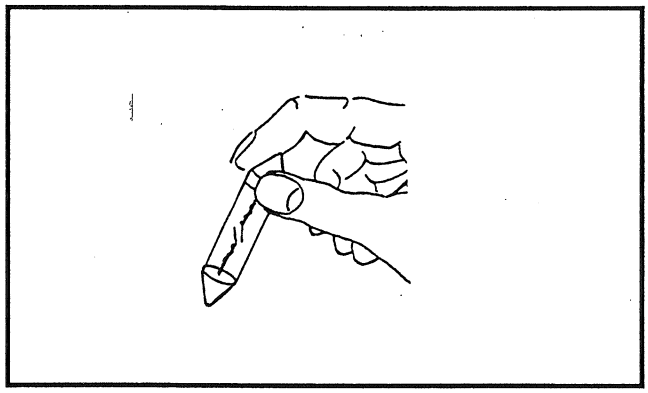


Fig. A

Design:

Glass tube closed by 2 metal caps on which 2 electrodes are secured.

Filling:

Rarefied air (approx. 3 hPa)

When a voltage of above 110 V (ignition voltage) is present between the electrodes, the gas close to the negative electrode glows (negative glow light).

In the experiments described in this book, one metal cap must always be held between your fingers. Discharge occurs via the body for high voltages.

This is not dangerous, because the currents which flow are very small.

Use: Screwdriver with pole indicator.

2. Friction rods made of PVC and acrylic glass 2 pairs (541 00)

When rubbed with rough paper (e.g. writing paper or newspaper), the acrylic glass rod becomes positively charged and the PVC rod negatively charged.

Paper is recommended as friction material in the experiment descriptions. If a better result can be obtained in individual cases using polyethylene friction material, this should be used.

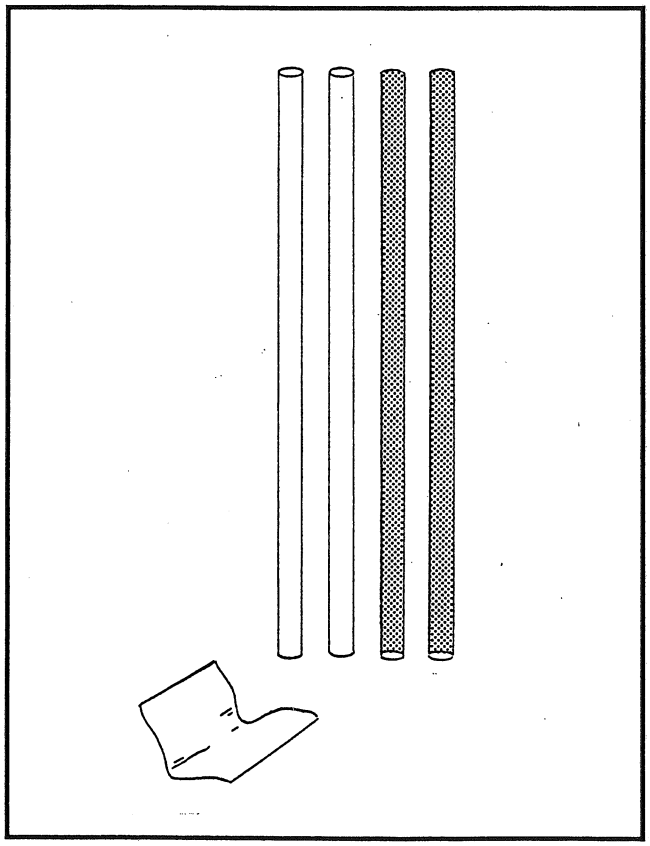


Fig. B

3. Faraday cup (546 12)

The Faraday cup acts as a charge store. Using the 4 mm plug, the cup can be plugged onto the electroscope (➤ 4.) or onto a PVC rod (➤ 2.).

The Faraday cup is free of fields in the bottom part of its interior (Faraday cage). Charges on the Faraday cup are located on its outer side (repellence of like charges). Electric charges can be completely discharged on the inside of the cup.

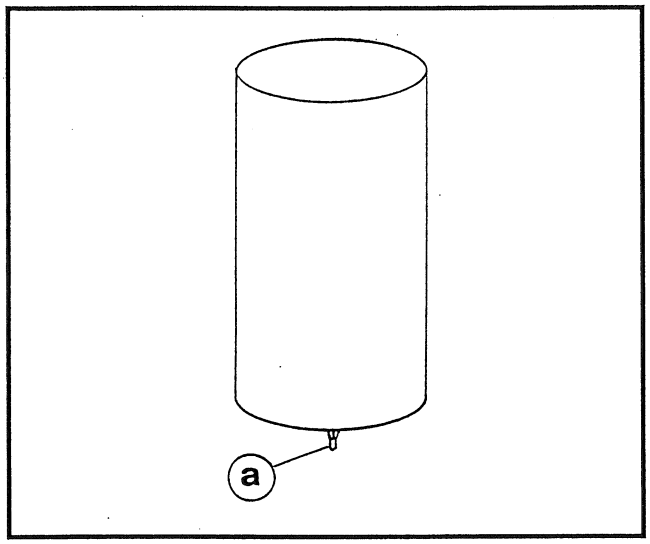


Fig. C

Exeriments on demonstration of the qualitative properties of the Faraday cup: ➤ Chapter 5.

4. Electroscope S (540 08)

In the electroscope S, either a metallized drinking straw or a straw acts as a pointer. It is shown that the surface conductivity of a straw is sufficient to guarantee functional capability. The equipment set includes 50 straws. Experiment 2.4 describes how a pointer for the electroscope can be made from a straw. The pointer deflection is based on the repellent force of charges with the same polarity. Simple model experiment: ➤ 2.3

Position (a): socket for plugging on the Faraday cup.

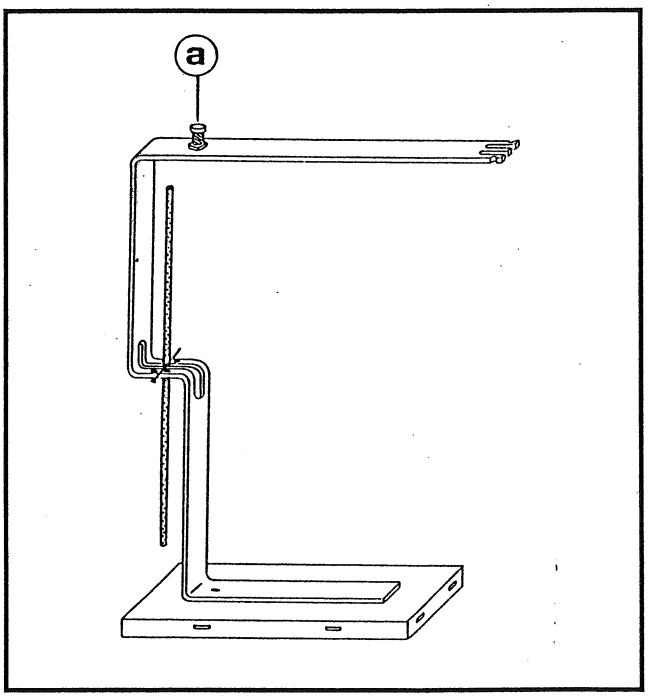


Fig. D

Students' sheet

Proof of charge types on friction rods with a glow lamp

Task: Charge friction rods electrostatically by rubbing and investigate the charges using a glow lamp.

Apparatus:

1 Pair of friction rods made of PVC and acrylic glass
1 Glow lamp

Friction material:

1 Sheet of rough paper

Notes on set-up:

Darken room.

Method:

Experiment 1:

Rub acrylic glass rod powerfully with paper.

Hold the glow lamp by the metal ring (cap) and touch the rod as shown in Fig. 1.

What do you observe?

Experiment 2:

Rub the PVC rod powerfully with paper.

Bring the rod into contact with the glow lamp (as shown in Fig. 1).

What do you observe?

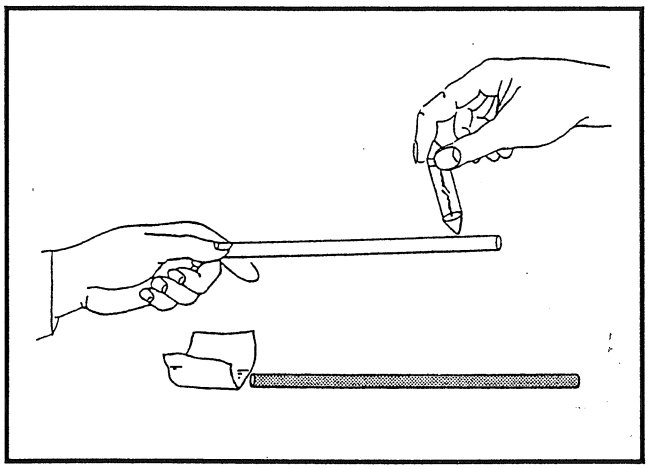


Fig. 1

Experiment results:

Give a summary.

Teacher's sheet

Proof of charge types on friction rods with a glow lamp

Experiment aims: Recognition that contact electricity caused by friction possesses two charge types which can be verified with a glow lamp.

Apparatus:

1 Pair of friction rods made of PVC and acrylic glass 541 00
1 Glow lamp, double-ended . . . . . from 505 41

Friction material:

1 Sheet of rough paper

Experiment results:

Experiment 1:

In the case of the **acrylic glass rod**, the glow lamp electrode **facing away** from the rod lights up.

Experiment 2:

In the case of the **PVC rod**, the glow lamp electrode **facing** the rod lights up.

The acrylic glass rod and PVC rod thus carry different charges after rubbing.

It is possible to distinguish between two charge types using the glow lamp.

Note:

As already known from other experiments, the **negative electrode** (cathode) of the glow lamp always lights up.

After rubbing with paper, the acrylic glass rod thus carries positive charges and the PVC rod negative charges.

Students' sheet 1

Proof of charge types on foils and sheets with a glow lamp

Task: Using the glow lamp, verify the charge types which are transferred to the induction plate by the polystyrene sheet and acetate foil.

Apparatus:

1 Glow lamp
1 Polystyrene sheet
1 Acetate foil
1 Induction plate 40 x 80 mm with insulating handle
1 Wool cloth

Preparing the experiment:

Darken the experiment location.

Method:

Experiment 1:

Cover the polystyrene sheet with the acetate foil (➤ Fig. 1)

Press on the foil and rub powerfully with the wool cloth. Then pull off the foil. Move the glow lamp up to the acetate foil as shown in Fig. 2.

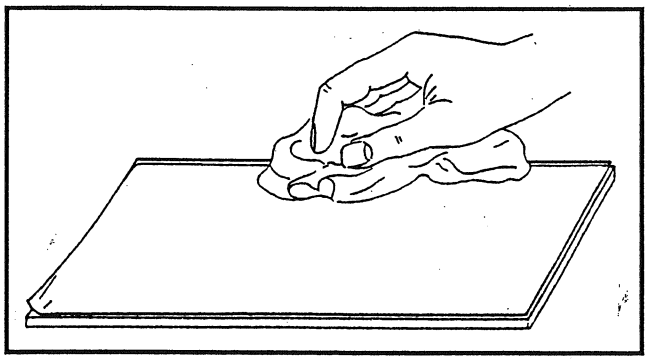


Fig. 1

Experiment 2:

Repeat experiment 1. However, now touch the foil directly with the glow lamp.

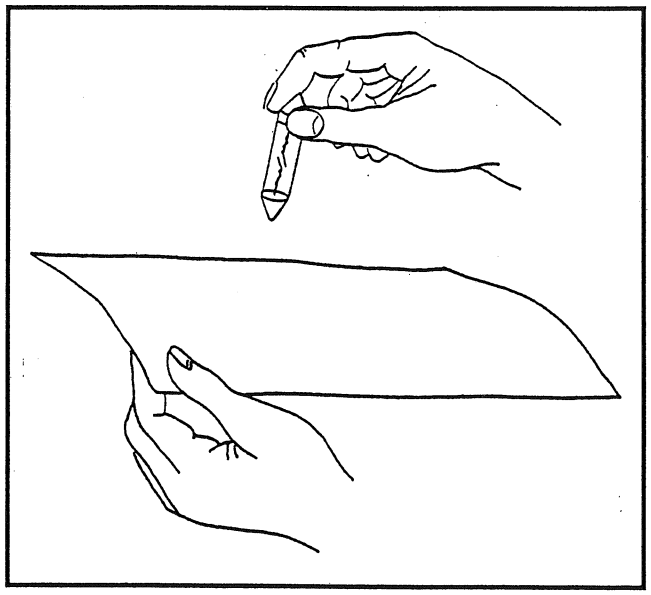


Fig. 2

Experiment 3:

Press on and powerfully rub the foil once again.

Rapidly pull off the foil and pass the induction plate over the polystyrene sheet as shown in Fig. 3.

Touch the induction plate lying on the polystyrene sheet with the glow lamp.

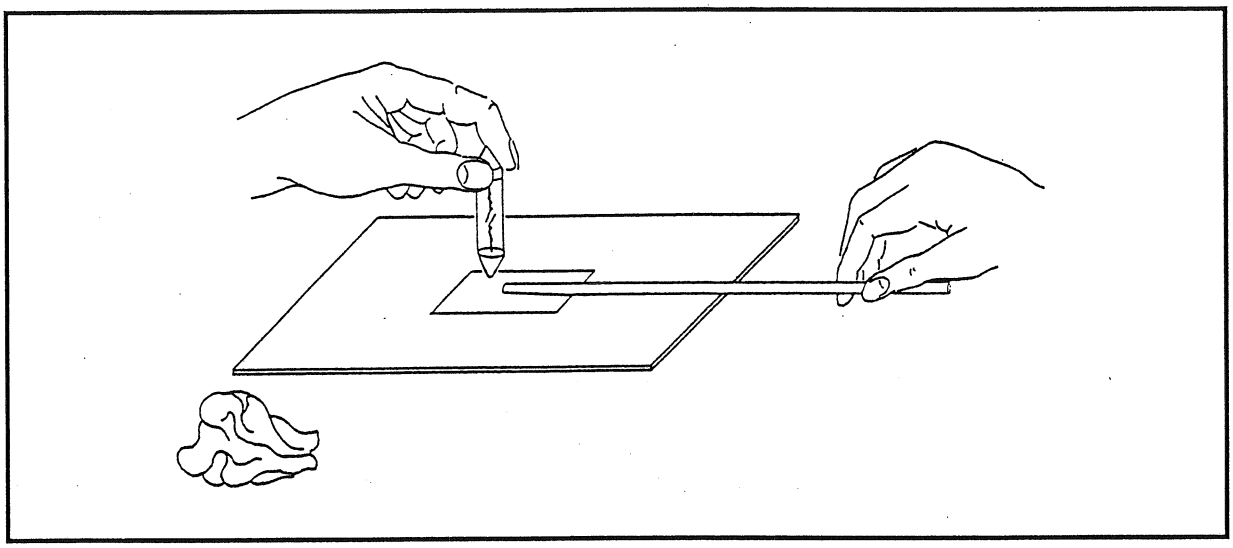


Fig. 3

Experiment 4:

Rub and pull off the foil as in experiment 3.

Then first lift the induction plate from the support surface and only then touch with the glow lamp.

Observations and explanations:

Teacher's sheet

Proof of charge types on foils and sheets with a glow lamp

Experiment aim: Explanation of the production of different charge types and verification of these using a glow lamp.

Apparatus:

1 Glow lamp, double-ended . . . . . from 505 41
1 Dielectric set 544 25
(needed from this:
1 Polystyrene sheet, 1 acetate foil)
1 Induction plate 40 x 80 mm
with insulating handle 542 51
1 Wool cloth

Observations:

Experiment 1:

The acetate foil sticks to the polystyrene sheet. The foil is reluctant to let itself be peeled off.

Hairs on the back of the hand stand up. There is crackling as a result of contact with the finger tips, for example. When the glow lamp is approached, the electrode facing away from the foil lights up.

Experiment 2:

When the foil is touched with the glow lamp, the electrode on the side facing the foil lights up.

Experiment 3:

When the induction plate on the polystyrene sheet is touched with the glow lamp, the electrode facing away lights up.

Experiment 4:

If the glow lamp is touched only after the plate is lifted off, the electrode facing the plate lights up.

Explanations:

Powerful pressing on and rubbing leads to charge separation (contact electricity).

The acetate foil is charged positively and the polystyrene sheet negatively.

Note:

The electrode which lights up on the glow lamp is negative.

If no direct contact is made with the charged foil or polystyrene sheet with the glow lamp, the other electrode lights up in each case. This is a result of electric induction.

Students' sheet

Contact electricity between clear adhesive tape and metal

Task: Check whether charges remain when a clear adhesive tape strip is pulled off the induction plate.

Apparatus:

1 Electroscope S
1 Induction plate with insulating handle
1 Strip of clear adhesive tape, approx. 10 cm long

Set-up:

➤ Fig. 1

Discharge the electroscope. How?

Stick the clear adhesive tape on the induction plate. Allow a little to project. Press on firmly everywhere.

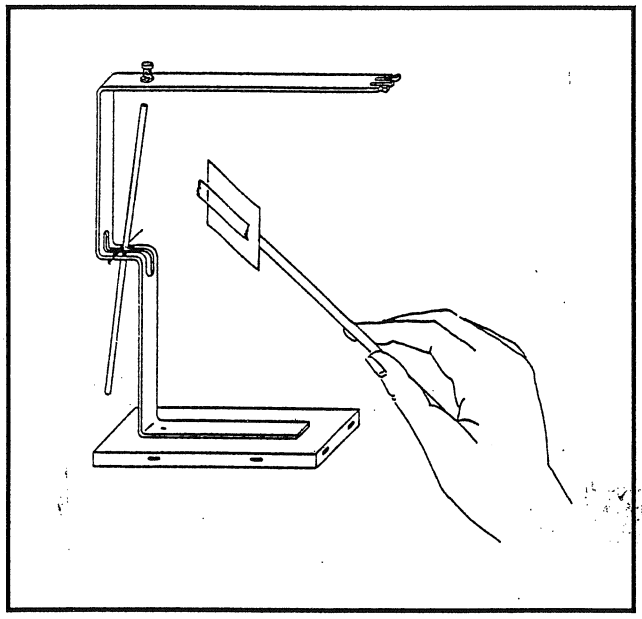


Fig. 1

Method:

Approach the induction plate to the electroscope pointer as shown in Fig. 1.

Hold the induction plate by the insulating handle, pull off the clear adhesive tape and do not touch the plate!

Approach the induction plate to the electroscope pointer as before.

Teacher's sheet

Contact electricity between clear adhesive tape and metal

Experiment aim: Verification that contact electricity occurs as a result of charge separation after separation of different adhering materials.

Apparatus:

1	Electroscope S	540 08
1	Induction plate with insulating handle	542 51
1	Strip of clear adhesive tape, approx. 10 cm long	

Set-up:

The electroscope can be discharged by touching it with a finger.

Result:

If the induction plate with pressed-on clear adhesive tape is moved up to the electroscope pointer, the latter does not react.

However, when the clear adhesive tape is removed, the pointer is significantly deflected.

Charge separation occurs between the metal and clear adhesive tape when the latter is pulled off. The induction plate thus carries a charge and exerts a force on the pointer owing to electric induction.

Students' sheet 1

Contact electricity generation by friction

Task: Rub the friction rods on different materials and verify the polarities of the electric charges caused as a result using the electroscope.

Apparatus:

1 Electroscope S
1 Faraday cup
1 Induction plate 40 x 80 mm with insulating handle
1 Pair of friction rods
1 Pair of scissors
1 Sheet of rough paper, approx. DIN A4

Set-up:

Cut an 8 cm x 25 cm strip from a sheet of paper. Wind the paper strip around the induction plate.

➤ Fig. 1

Keep the second sheet of paper ready for rubbing.

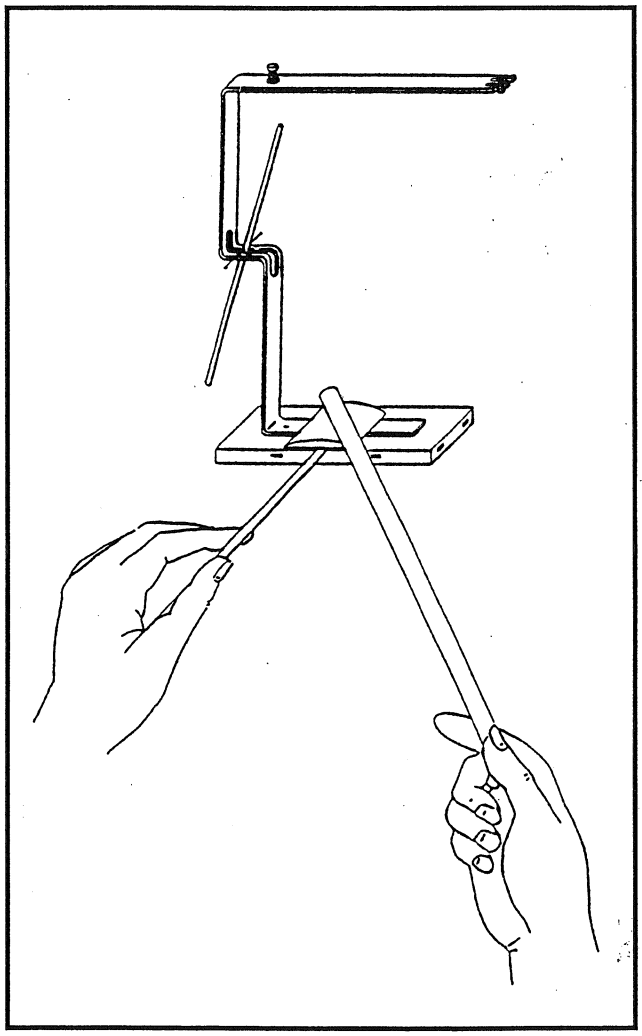


Fig. 1

Method:

Experiment part 1:

Investigation of an acrylic glass rod rubbed with paper for charge. Discharge the electroscope by touching with a finger.

Rub the acrylic glass rod on paper (Fig. 2). Can charges be detected on the acrylic glass rod with the electroscope?

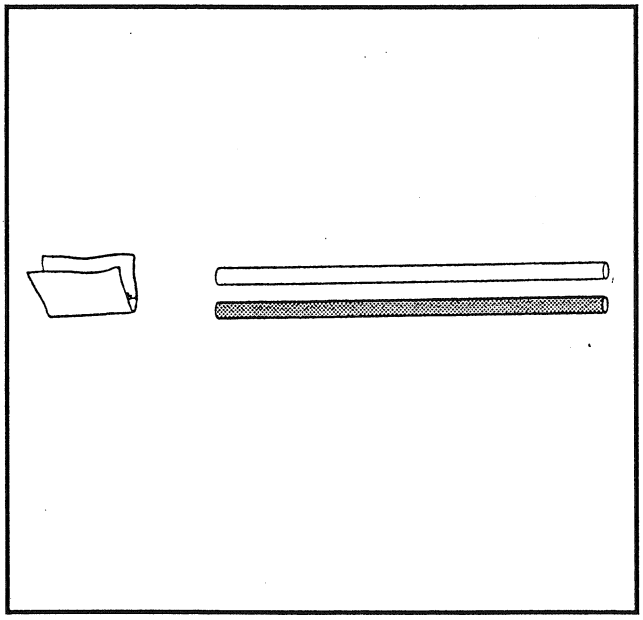


Fig. 2

Experiment part 2:

Investigation of the charge polarity of paper which is rubbed with an acrylic glass rod.

Press the induction plate wrapped with paper on the metal base of the electroscope as shown in Fig. 1.

Powerfully rub the paper with the acrylic glass rod.

Alternately rub the wrapped-round paper and the back of your hand with the acrylic glass rod.

Experiment part 3:

Investigation of the charge polarity of paper which is rubbed with a PVC rod.

Alternately rub the wrapped-round paper and the back of your hand with the PVC rod.

Experiment part 4:

Investigation of the charge polarity of a PVC rod rubbed on paper.

Rub the PVC rod with paper (Fig. 2) and transfer the charges to the electroscope.

Observations and explanations:

- How can the occurrence of charges be explained?
- Which charge polarities occur in the individual experiment parts if the charge of the acrylic glass rod rubbed on paper is defined as positive?
- Can specific charge polarities be assigned to various materials?

Teacher's sheet 1

Contact electricity generation by friction

Experiment aim: Recognition that

- when different materials touch each other intensively, they are both charged with a different charge polarity
- the polarity of the charge is not typical for a specific material, but depends on the material of the two objects touching each other.

Apparatus:

1	Electroscope S	548 08
1	Faraday cup	546 12
1	Induction plate 40 x 80 mm with insulating handle	542 51
1	Pair of friction rods	541 00
1	Sheet of rough paper	

Observations and explanations:

Electrically neutral bodies contain positive and negative charges which cancel each other out.

When two different materials are rubbed together, electric neutrality of the two bodies may be disturbed. They are charged with opposing polarity.

In experiment part 1

the electroscope receives the positive charge of the acrylic glass rod rubbed on the paper.

Experiment part 2

proves the negative polarity of the paper rubbed by the acrylic glass rod. The pointer deflection of the positively charged electroscope is reduced.

Note:

It is necessary to remove the separated charges from the acrylic glass rod (by touching against the back of the hand) so that further charges can be separated.

Experiment part 3

shows that the polarity of paper changes if the acrylic glass rod is replaced by the PVC rod:

The pointer deflection of the positively charged electroscope is increased, i.e. the paper is positively charged.

Experiment part 4

shows that the PVC rod rubbed on paper possesses a charge with opposite polarity to the paper.

The pointer deflection of the positively charged electroscope is reduced.

The PVC rod is therefore negatively charged.

Conclusion:

- When two uncharged materials are rubbed against each other, they charge each other with opposite polarity.
- It is not possible to assign a specific charge polarity to a specific material (in the example, paper).

Students' sheet 1

Forces acting between charges

Task: Investigate the forces acting between electric charges.

Apparatus:

1 Electroscope S
1 Pair of plastic clips
2 Pairs of friction rods made of PVC and acrylic glass

Friction material:

1 Sheet of rough paper

Required only in experiment 5:
1 Bunsen burner for butane gas
1 Butane gas bottle

Set-up:

Attach the plastic clip to the center of the PVC rod as shown in Fig. 1, e.g. by pushing on from the rod end.

Rub one side of the PVC rod powerfully with paper.

➤ Fig. 1)

Suspend rod as shown in Fig. 2.

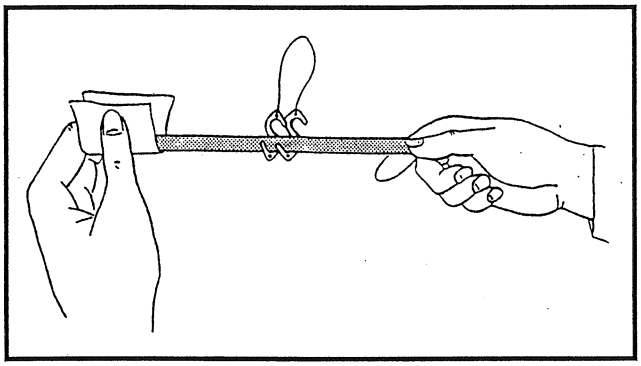


Fig. 1

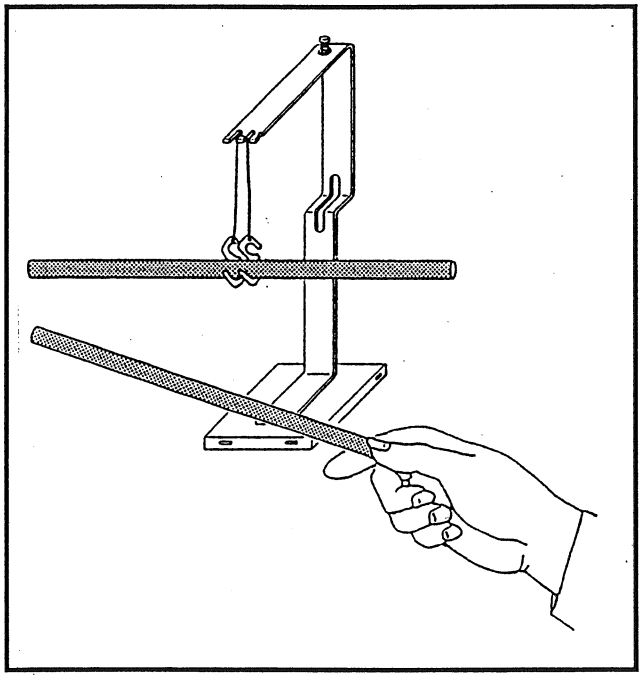


Fig. 2

Method:

Experiment 1:

Also rub the second PVC rod (➤ Fig. 1).

Move the rubbed ends of the two rods close to each other.

Experiment 2:

Approach the suspended rod with a rubbed acrylic glass rod instead of the second rubbed PVC rod (➤ Fig. 3).

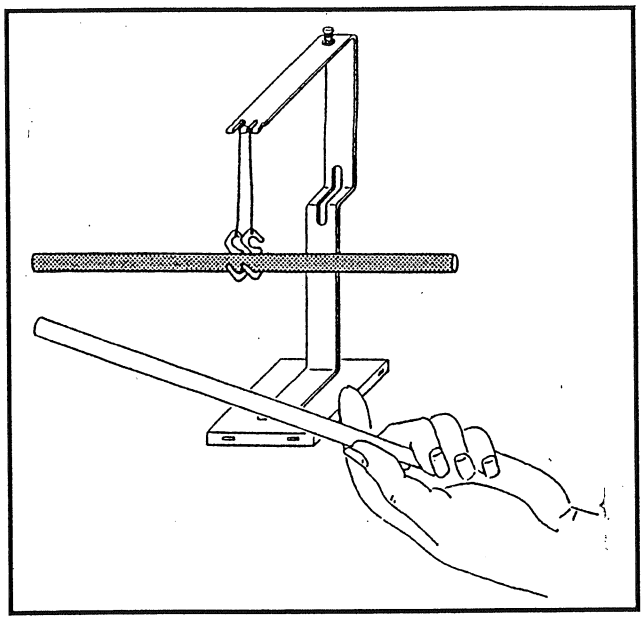


Fig. 3

Experiment 3:

Approach two acrylic glass rods which have been rubbed with paper as shown in Fig. 4.

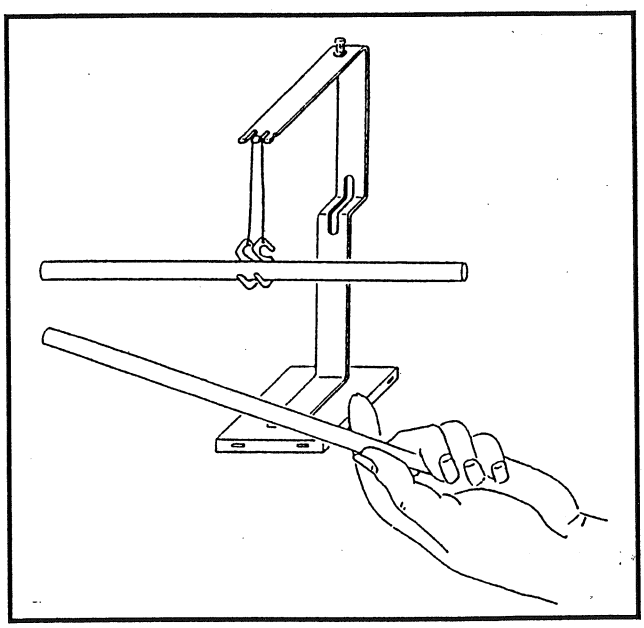


Fig. 4

Experiment 4:

In the experiment set-up as shown in Fig. 4, approach the end of the rubbed acrylic glass rod with a rubbed PVC rod.

Experiment 5:

Discharge the PVC rod and the acrylic glass rod over a non-smoking burner flame.

Attach plastic clips to the center of one rod (e.g. the PVC rod) as shown in Fig. 5. Knock the ends of the two rods together powerfully several times.

Suspend the rod with the plastic clips without touching the knocked rod end. Bring the two ends which have been knocked together close to each other.

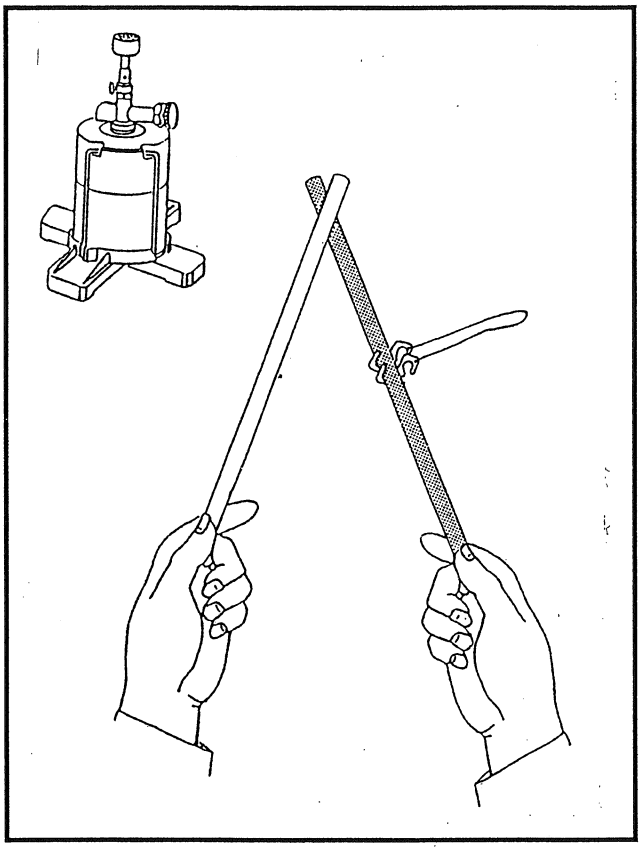


Fig. 5

Observations and evaluation:

Teacher's sheet

Forces acting between charges

Experiment aim: It must be found out that

- two distinguishable charge types are caused by rubbing
- charges of the same type repel each other
- charges of different types attract each other

Apparatus:

1	Electroscope S	540 08
1	Pair of plastic clips	541 06
2	Pairs of friction rods made of PVC and acrylic glass	541 00

Friction material:

1 Sheet of rough paper

Required only in experiment 5, if the friction rods are verifiably not neutral:

1	Bunsen burner for butane gas . . .	666 711
1	Butane gas bottle . . . . . from	666 712

Result:

Experiments 1 to 4:

The ends rubbed on the paper repel each other if the rods are of the same material. They attract each other if the materials differ.

The PVC rod and acrylic glass rod are charged with opposing polarity by rubbing.

Like charges repel each other. Unlike charges attract each other.

Experiment 5:

Note:

Neutralization of the friction rods can also be performed as a demonstration (in front of the class).

Instead of rubbing with paper, the neutral PVC rod and the neutral acrylic glass rod are charged here by knocking together.

The rod ends carry different charges as a result of charge separation.

Different charges attract each other.

Students' sheet 1

Forces acting on a charged pendulum pair

Task: Observe the mutual influence of identically charged bodies (pendulum pair, friction rod) on each other.

Apparatus:

1 Electrostatic pendulum pair
1 Electroscope S (without pointer)
1 Pair of friction rods made of PVC and acrylic glass

Friction material:

1 Sheet of paper

Set-up:

Suspend the pendulum pair as shown in Fig. 1.

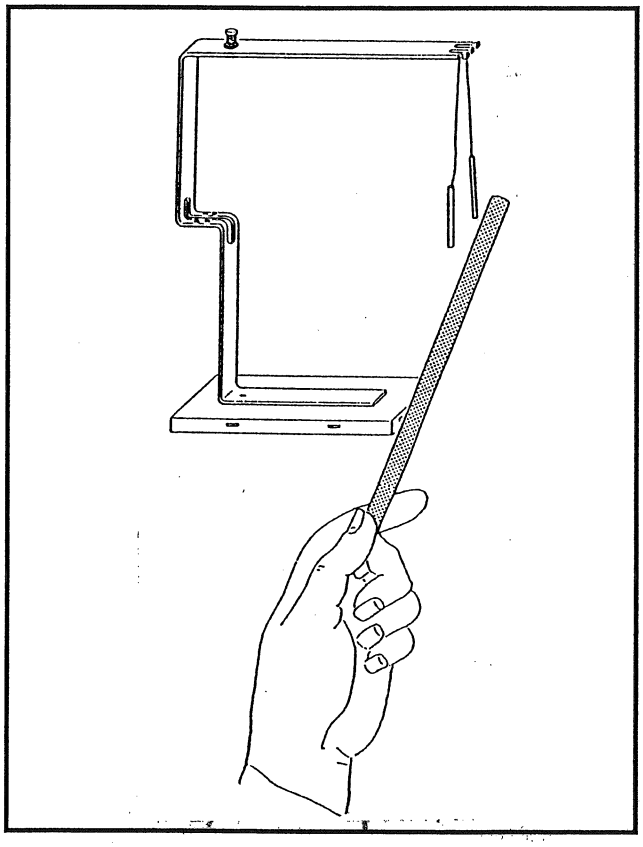


Fig. 1

Method:

Experiment 1:

Rub the PVC rod with paper.

Touch both pendulums with the rubbed rod.

Bring the rod close to the pendulums and hold between the pendulums.

Experiment 2:

As experiment 1, but now rub the acrylic glass rod with paper.

Touch both pendulums with the rubbed rod.

Bring the rod close to the pendulums and hold between the pendulums.

Observations and evaluation:

Teacher's sheet

Forces acting on a charged pendulum pair

Experiment aim: It must be discovered that repellent forces act between identically charged bodies (principle of the electroscope)

Apparatus:

1	Electrostatic pendulum pair	540 07
1	Electroscope S (without pointer)	540 08
1	Pair of friction rods made of PVC and acrylic glass . .	541 00

Friction material:

1 Sheet of paper

Result:

The pendulums charged using the rubbed PVC rod or acrylic glass rod repel each other.

They are violently repelled by the friction rod which charged the pendulums.

Note:

The experiment result is independent of the charge polarity. The principle of the electroscope is demonstrated.

Further experiments with the pendulum pair ➤ 3.5

Model of an electroscope

Task: Build and demonstrate a simple model of an electroscope.

Apparatus:

1 Stand rod, 25 cm
1 Stand foot
1 Pair of friction rods made of acrylic glass and PVC
1 Strip of aluminium foil approx. 10 cm long, 3 mm wide
1 Pair of scissors
Clear adhesive tape, approx. 4 cm

Friction material:

1 Sheet of rough paper

Set-up:

➤ Fig. 1

Stick the metal strip to the top end of the stand rod using clear adhesive tape.

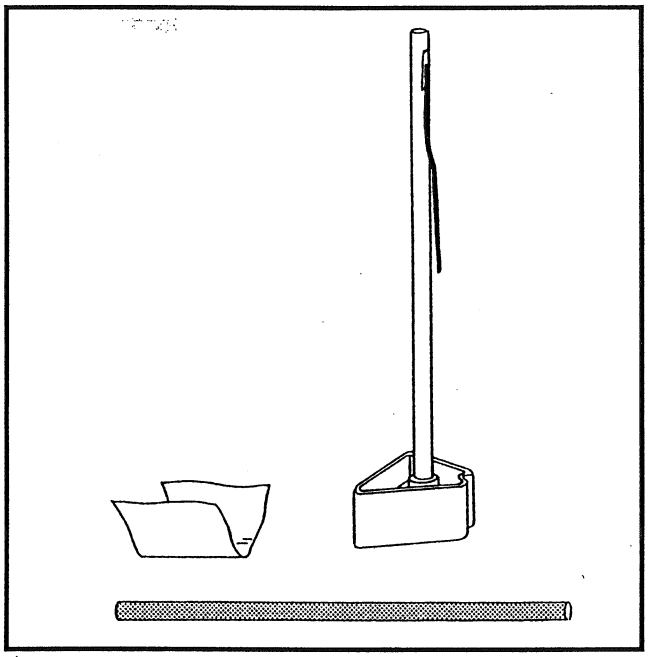


Fig. 1

Method:

Experiment 1:

Rub the friction rod made of PVC with paper.

Move the PVC rod up and down parallel to the stand rod without touching the latter.

Then touch the stand rod with your finger.

Experiment 2:

Rub the PVC friction rod on the paper once more and brush over the stand rod. Then rub the acrylic glass rod with paper and touch the stand rod with it.

Observations and explanations:

Teacher's sheet

Model of an electroscope

Experiment aim: Building a simple model of an electroscope and explanation of its principle of operation

Apparatus:

1	Stand rod, 25 cm	301 26
1	Stand foot . . . . . from	301 23
1	Pair of friction rods made of acrylic glass and PVC . .	541 00
1	Strip of aluminium foil approx. 10 cm long, 3 mm wide	
1	Pair of scissors	667 107
	Clear adhesive tape, approx. 4 mm	

Friction material:

1 Sheet of rough paper

Observations and explanations:

Experiment 1:

The metal strip is repelled by the stand rod.

Reason:

The stand rod and metal strip are charged with the same charge.

(In this case negative).

Like charges repel each other.

When the rod is touched with a finger, the deflection is cancelled out.

Reason: Discharge via the human body.

Experiment 2:

If the model electroscope charged by the PVC rod is touched with the rubbed acrylic glass rod, the deflection goes back to zero.

The acrylic glass rod carries the opposing charge (namely positive). The charges cancel each other out

When a further charge is applied, the metal strip is repelled by the stand rod again, since like charges repel each other.

Note:

The principle of operation of an electroscope is based on the repellence principle of identical charges.

Principle of electroscope operation

Task: Build an electroscope and explain its principle of operation

Apparatus:

1 Electroscope S
1 Straw as a pointer
1 Needle
1 Pair of friction rods made of PVC and acrylic glass
1 Pair of scissors
1 Ruler or meter rule

Friction material:

1 Sheet of rough paper

Set-up:

Production of the electroscope pointer:

➤ Fig. 1

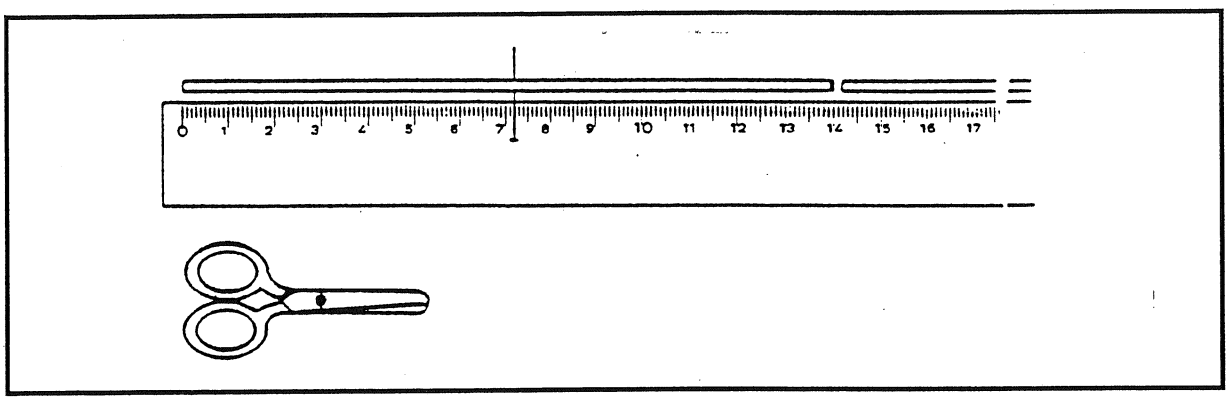


Fig. 1

Shorten the straw to a length of 14 cm; push the needle through the straw perpendicularly up to half-way 2 mm away from the center (i.e. at 7.2 cm).

Suspend the pointer in the electroscope housing ➤ Fig. 2.

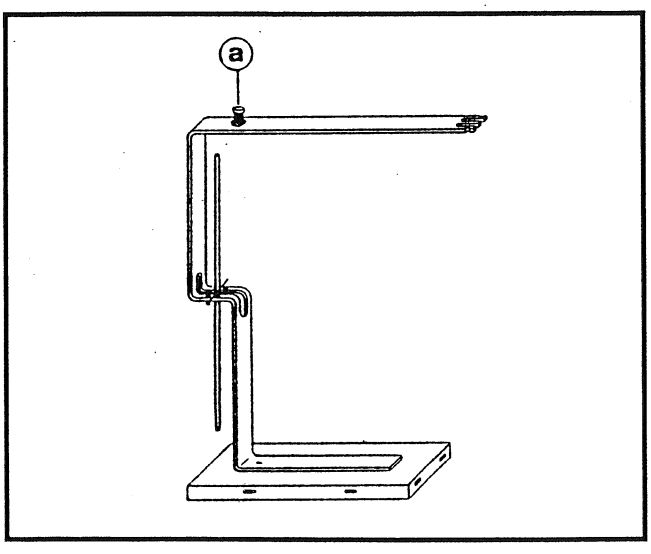


Fig. 2

Method:

Experiment 1:

Rub the acrylic glass rod with paper (➤ Fig. 3).

Brush the rod over point (a) on the electroscope ➤ Fig. 2.

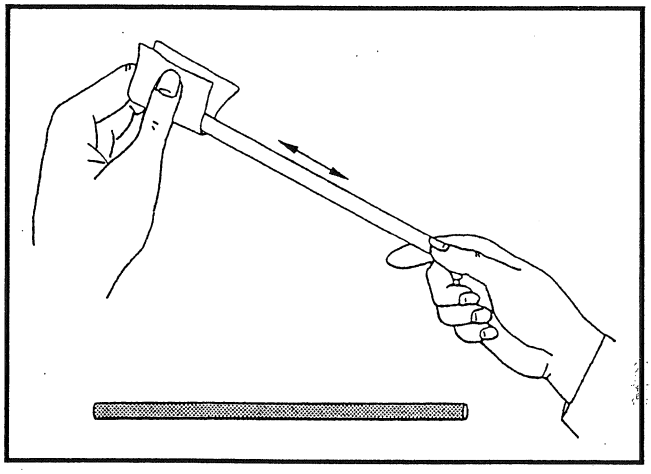


Fig. 3

Experiment 2:

Touch the metal electroscope housing with your finger.

Experiment 3:

Rub the PVC rod with paper and touch the electroscope with it at point (a).

Experiment 4:

Rub the PVC rod and acrylic glass rod with paper.

Touch point (a) of the electroscope first with one rod and then with the other one.

Observations and evaluation:

Teacher's sheet 1

Principle of electroscope operation

Experiment aims:

- Production of a pointer for the electroscope
- Awareness that the electroscope indicates the magnitude of a charge but not its polarity. The students should be able to give the reason for this.
- Knowledge of the simple possibility of discharging the electroscope by touching it.
- Recognition that it is possible to distinguish polarities using a charged electroscope.

Apparatus:

1	Electroscope S	540 08
1	Straw as pointer from	200 67 491
1	Needle	241 24 104
1	Pair of friction rods made of PVC and acrylic glass	541 00
1	Pair of scissors	667 107
1	Ruler or meter rule, e.g.	311 04

Friction material:

1 Sheet of rough paper

Set-up:

Production of the electroscope pointer:

One of the normal straws should be used for this task and not the metallized drinking straw.

Results:

Experiments 1 and 2:

The electroscope pointer is deflected in both cases.

The amount of the pointer deflection changes if more or less charge is applied.

It is not possible to determine the charge polarity from the electroscope deflection alone, since the deflection is caused by like charges repelling each other.

Experiment 3:

The electroscope can be discharged very quickly by touching it with a finger.

Experiment 4:

The electroscope charged with one of the friction rods can be discharged again by touching it with the other rod.

The electroscope is charged up again if it is touched once more.

Explanation:

The PVC rod and acrylic glass rod carry charges of opposing polarity.

Charges of opposing polarity can neutralize each other.

Induction phenomena with conductors and non-conductors

Task: Observe the effect of charged bodies (friction rods, acetate foil) on paper shreds, aluminium balls and pieces of cotton wool.

Apparatus:

1 Pair of friction rods made of PVC and acrylic glass
1 Sheet of writing paper
1 Aluminium foil approx. 10 cm^2
1 Wool cloth

Friction material:

1 Sheet of rough paper

Preparation:

Produce some shreds of paper and small pieces of cotton wool. Tear out pieces with a size of approx. 1 cm^2 from the aluminium foil and form balls.

Method:

Experiment 1:

Rub the acrylic glass rod with paper.

Hold the rod over the paper shreds and pieces of cotton wool as shown in Fig. 1. Repeat the experiment with the PVC rod.

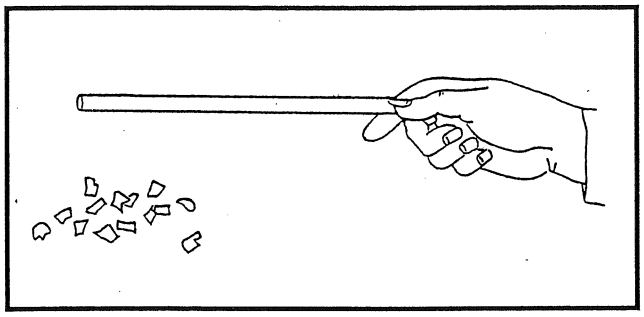


Fig. 1

Experiment 2:

➤ Fig. 2

Rub the acrylic glass rod with paper.

Place a ball of aluminium foil on a sheet of paper. Approach this with a friction rod from above. Repeat the experiment with the PVC rod.

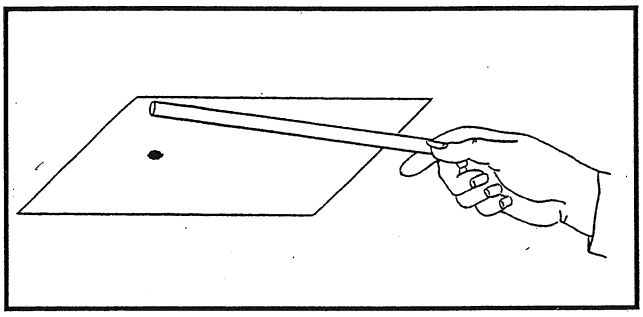


Fig. 2

Experiment 3:

Place the foil on the table and rub powerfully with the wool cloth.

Pull off the foil abruptly and first hold it over the balls of aluminium foil, then over the paper shreds and then over the pieces of cotton wool.

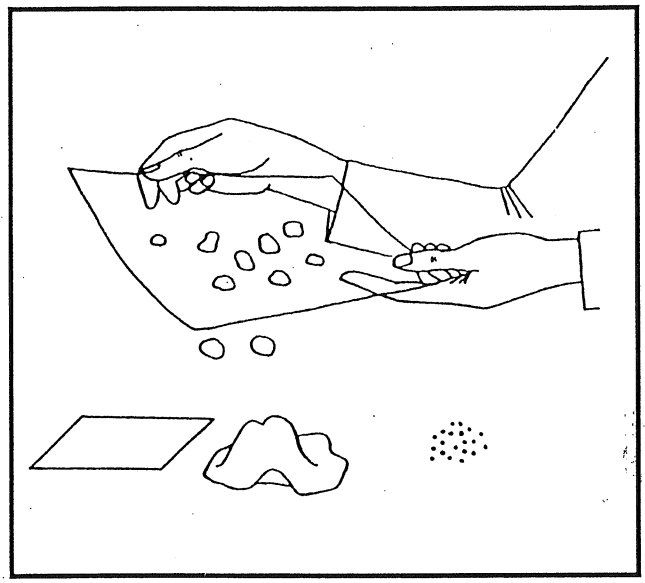


Fig. 3

Observations and explanations:

Teacher's sheet 1

Induction phenomena with conductors and non-conductors

Experiment aim: The student should know and be able to explain the action of the forces of charged bodies (friction rods, acetate foil) on paper shreds, aluminium balls and pieces of cotton wool.

Apparatus:

1 Pair of friction rods made of PVC and acrylic glass 541 00
1 Sheet of writing paper
1 Aluminium foil approx. 10 cm^2
1 Wool cloth

Friction material:

1 Sheet of rough paper

Observations and explanations:

Experiment 1:

The paper shreds and pieces of cotton wool are attracted by both of the friction rods and adhere to them. Explanation:

Charge displacement occurs in the paper shreds and pieces of cotton wool. The side facing the friction rod is charged with the opposite polarity by induction, while the side facing away from the friction rod is charged with the same polarity. An attractive force results from the greater proximity of the opposing charges. The particles adhere because they are very light and become charged with the same polarity only very slowly as poor conductors.

Experiment 2:

➤ Fig. 2

Observation:

The ball made of aluminium foil is attracted by the friction rod and violently repelled immediately after contact.

As soon as it has touched the sheet of paper on the table, it is attracted by the friction rod again. This procedure repeats itself several times.

Finally, the ball adheres lightly to the friction rod.

Explanation:

The ball made of aluminium foil is attracted by the friction rod as a result of induction. Since it is not very heavy, it jumps to the friction rod. As a good electric conductor, it is charged with the same charge very quickly here. Since like charges repel each other, the ball is violently repelled.

It is discharged by the paper on the table. This procedure is repeated as long as the charge given off by the friction rod is sufficiently large. When the charge is low, the attraction resulting from induction may be greater than repellence as a result of like charging. The ball then adheres to the friction rod.

Experiment 3:

This experiment is a summary of experiments 1 and 2 with a foil instead of a friction rod.

The observations and explanations thus correspond to the above.

Students' sheet

Electrostatic charging of hair

Task: Observe the effect of an acetate foil rubbed with a wool cloth on dry hair.

Apparatus:

1 Acetate foil
1 Wool cloth

Head with grease-free, dry hair; most suitable: freshly washed hair

Method:

Place the acetate foil on the table and rub powerfully with the wool cloth. Pull off the foil abruptly and hold over the head.

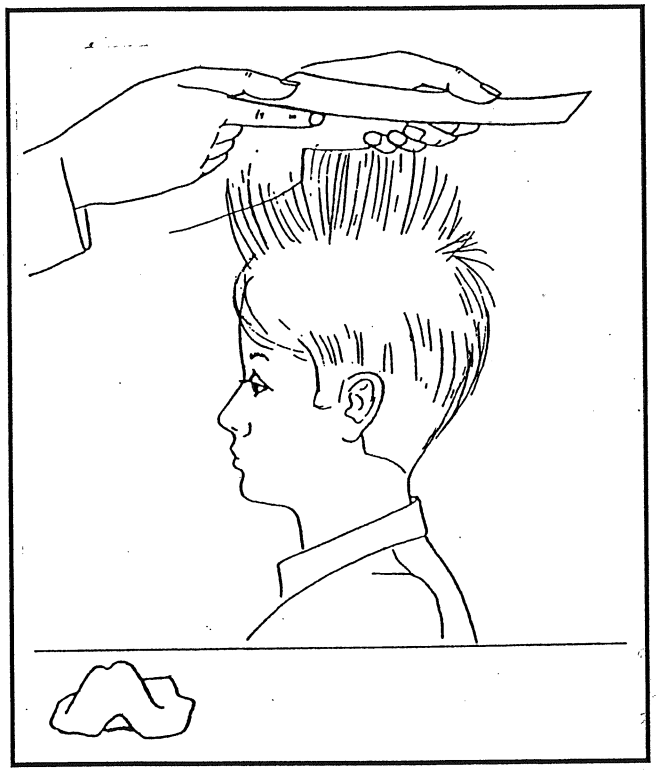


Fig. 1

Observations and explanation:

Teacher's sheet

Electrostatic charging of hair

Experiment aim: The student should be able to explain the action of forces from an electrostatically charged foil on dry hair.

Apparatus:

1 Acetate foil . . . . . from 544 25
1 Wool cloth

Head with grease-free, dry hair, most suitable: freshly washed hair

Result:

The hair ends are charged with opposing polarity to the foil and are therefore attracted by it.

Students' sheet 1

Forces caused by induction

Task: Demonstrate the action of the forces of a rubbed PVC rod on an insulated metal plate.

Apparatus:

1 Electroscope S
1 Pair of plastic clips
1 Induction plate 40 x 80 mm
1 Pair of friction rods made of PVC and acrylic glass

Friction material:

1 Sheet of rough paper

Preparation:

Attach the plastic clips to the center of the PVC rod as shown in Fig. 1. This can be done particularly easily by pushing in the rod.

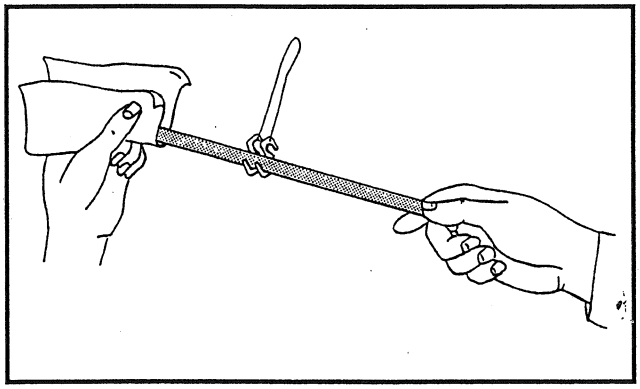


Fig. 1

Method:

Rub the rod end (➤ Fig. 1) powerfully with paper. Suspend the rod ➤ Fig. 2.

Free the induction plate from possible charges by touching it with a finger.

Hold the induction plate close to

a) the rubbed

b) the non-rubbed rod end

as shown in Fig. 2.

Do not touch the rod end, however.

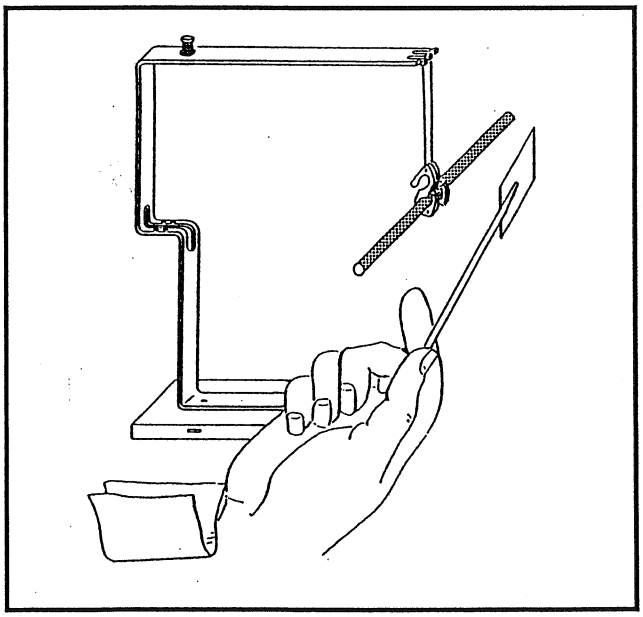


Fig. 2

Observation and explanation:

Teacher's sheet

Forces caused by induction

Experiment aim: It should be recognized that a charged friction rod causes charges of opposing polarity on a neutral metal plate.

(Induction, mirror charging)

Apparatus:

1	Electroscope S	540 08
1	Pair of plastic clips	541 06
1	Induction plate 40 x 80 mm with insulating handle	542 51
1	Pair of friction rods made of PVC and acrylic glass	541 00

Friction material:

1 Sheet of rough paper

Results:

The charged rod end is attracted by the neutral metal plate.

Explanation:

Charge separation occurs perpendicular to the metal plate as a result of induction:

Like charges are repelled, unlike charges are attracted.

Owing to the small distances from the unlike charges, the overall effect is an attractive force.

Note:

It can be verified that the force action is as if the rod reflected on the metal surface were acting there with the opposing charge sign (mirror charging).

Students' sheet 1

Induction phenomena on a pointer

Task: Investigate the effect of a charged friction rod on a neutral metal pointer.

Apparatus:

1 Electroscope S
1 Pair of friction rods made of PVC and acrylic glass

Friction material:

1 Sheet of paper

Set-up:

➤ Fig. 1

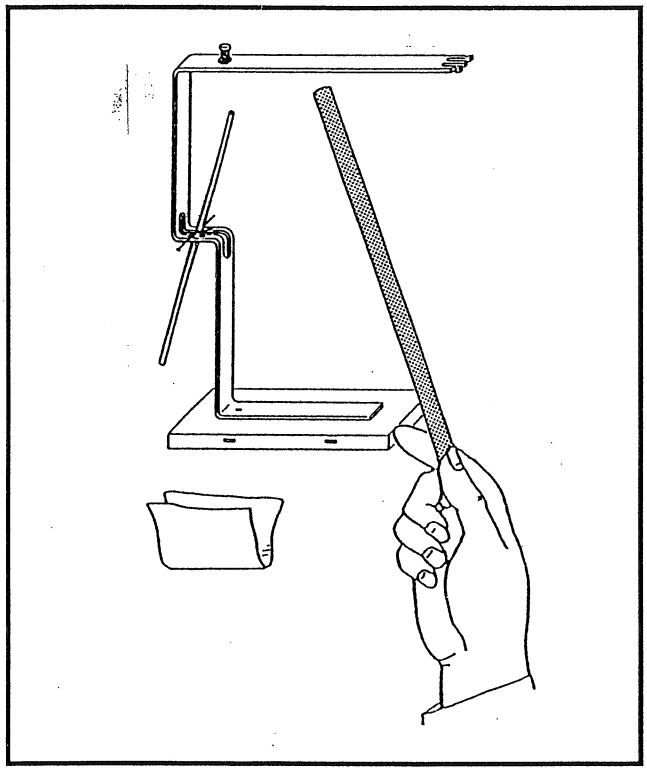


Fig. 1

Method:

Experiment 1:

Discharge the pointer by touching it with a finger.

Rub the PVC rod with paper and slowly move it close to the top pointer end.

Experiment 2:

Discharge the pointer by touching it with a finger.

Rub the acrylic glass rod with paper and slowly move it close to the top pointer end.

Observation and evaluation:

Teacher's sheet

Induction phenomena on a pointer

Experiment aim: Understanding that charged bodies exert a force on electrically neutral bodies irrespective of their polarity.

Understanding that the force action is a result of charge separation.

Apparatus:

1	Electroscope S	540 08
1	Pair of friction rods made of PVC and acrylic glass	541 00

Friction material:

1 Sheet of rough paper

Results:

Experiments 1 and 2:

Both the PVC rod and the acrylic glass rod attract the electrically neutral pointer.

Explanation:

The pointer contains two charge types (positive and negative) which cancel each other out in an electrically neutral body.

When a charged body is approached, charges of the same polarity are repelled and charges of unlike polarity attracted. Charge displacement occurs.

Attraction results owing to the greater proximity of the charges of opposing polarity.

Students' sheet 1

Electric induction on a pendulum pair

Task: Investigate how an electrically neutral pendulum pair reacts when it is close to a charged friction rod.

Apparatus:

1 Electroscope S (without pointer)
1 Electrostatic pendulum pair
1 Pair of friction rods made of PVC or acrylic glass

Friction material:

1 Sheet of rough paper

Set-up:

Suspend the pendulum pair as shown in Fig. 1. Briefly touch both pendulums with a finger to discharge them.

Method:

Experiment 1:

Rub PVC rod with paper.

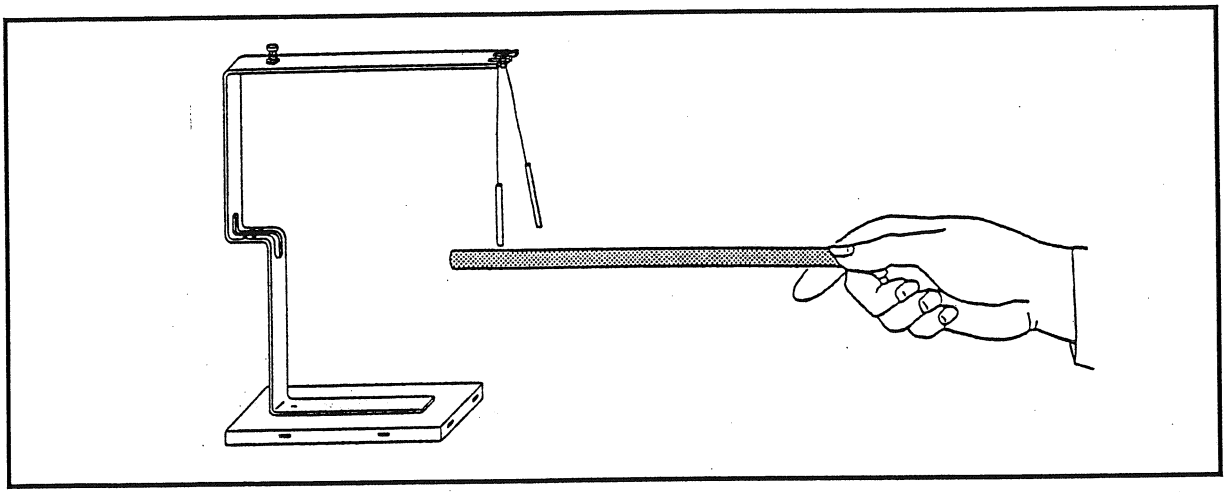


Fig. 1

As shown in Fig. 1, slowly approach the rod end to the pendulums from below, moving it to and fro sideways.

Do not touch!

If necessary, repeat experiment.

Experiment 2:

Touch both pendulums with a finger. Move the acrylic glass rod rubbed with paper to and fro sideways and approach to the pendulum from below.

If the rod touches the pendulum, repeat the experiment.

Experiment 3:

Discharge both pendulums as before.

Rub the PVC rod and acrylic glass rod with paper.

Without touching the pendulums, move the two friction rods about close to the pendulum pair.

Observation and evaluations:

Teacher's sheet

Electric induction on a pendulum pair

Experiment aim: It should be recognized that charges already exist in electrically neutral bodies which can be separated by the action of charges in the environment.

(Phenomenon of "electric induction")

Apparatus:

1 Electroscope S (without pointer) . . 540 08
1 Electrostatic pendulum pair 540 07
1 Pair of friction rods made of PVC and acrylic glass

Friction material:

1 Sheet of rough paper

Results:

Experiments 1 and 2:

The pendulum ends follow the friction rod as it is moved from side to side.

Both pendulums are attracted by the friction rod.

If the friction rod is brought closer, the two pendulums repel each other violently.

Explanation:

Charges accumulate at the pendulum ends owing to charge separation which possess opposite polarity to that of the rod.

The ends charged with opposite polarity to that of the friction rod are attracted by the friction rod.

Charge separation in the pendulums results in charges of the same polarity being opposite each other. These repel each other.

Experiment 3:

Experiments 1 and 2 can be performed with the acrylic glass rod in the same way. The pendulum ends which repel each other over one friction rod are repelled by the other friction rod. This confirms the like polarity of the charges.

Students' sheet

Electric induction in a water stream

Task: Observe how electric charge influences a water stream.

Apparatus:

1 Pair of friction rods made of acrylic glass and PVC
1 Beaker
1 Overflow vessel

Friction material:

1 Sheet of rough paper
approx. 200 ml water

Preparation:

Fill the overflow vessel with water up to the overflow opening.

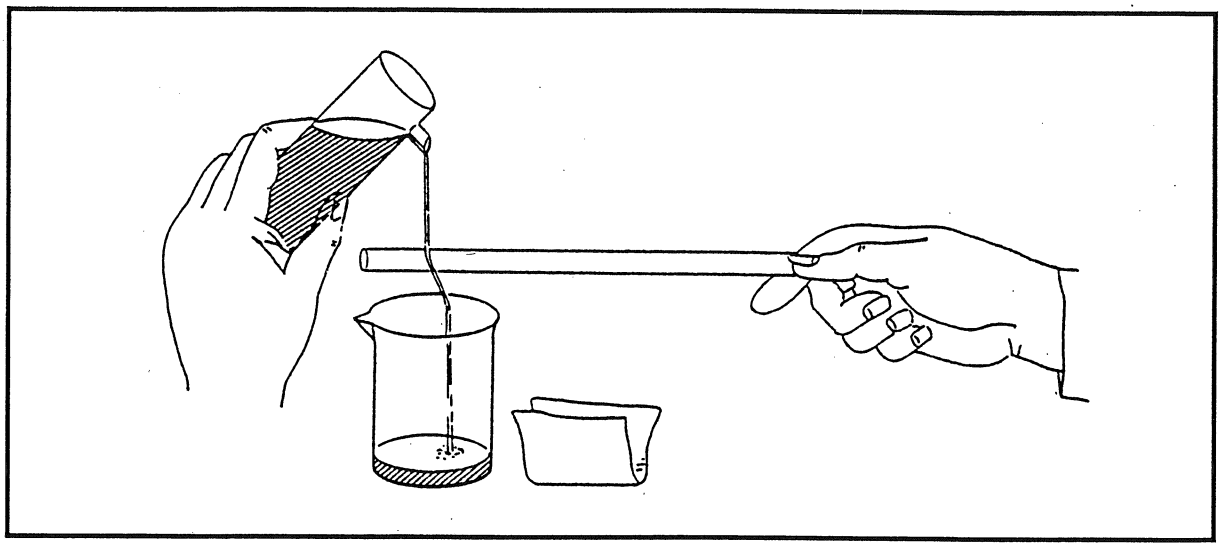


Fig. 1

Method:

Rub the friction rod made of acrylic glass or PVC powerfully with paper.

Pour the water out of the overflow vessel into the beaker in a fine water stream.

Hold the friction rod close to the water stream.

Observation and explanation:

Teacher's sheet

Electric induction in a water stream

Experiment aim: The student should be able to demonstrate the effect of deflection of a non-charged water stream by a charged friction rod and to interpret this as an induction phenomenon.

Apparatus:

1	Pair of friction rods made of acrylic glass and PVC	541 00
1	Beaker	664 103
1	Overflow vessel	362 04

Friction material:

1 Sheet of rough paper
approx. 200 ml water

Observation:

The water stream is considerably deflected by the rubbed friction rod made of acrylic glass or PVC.

Explanation:

Charges of opposing polarity are induced in the water stream as a result of the external charge.

The experiment can be demonstrated particularly simply and effectively with a fine water stream from a tap(➤ Fig. 2).

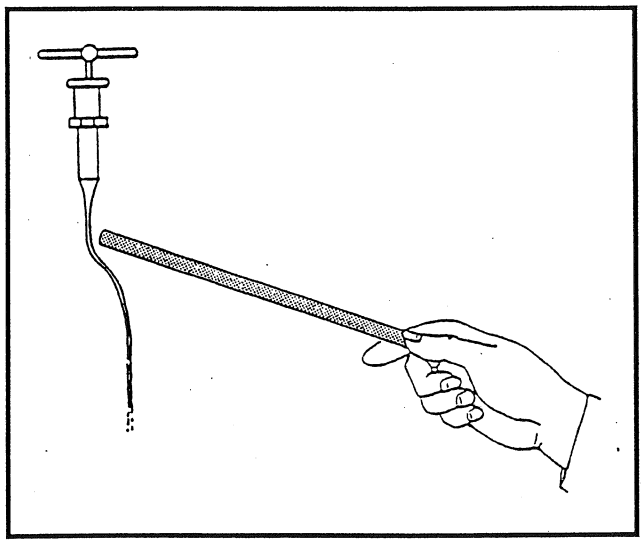


Fig. 2

Students' sheet 1

Induction phenomena on an electroscope caused by friction rods

Task: Observe the pointer deflection of a charged electroscope when charged friction rods are brought close to the housing.

Apparatus:

1 Electroscope S
1 Pair of friction rods made of acrylic glass and PVC

Friction material:

1 Sheet of rough paper

Method

Experiment 1:

Charge the PVC rod by rubbing it with paper. Touch the electroscope at the top so that the pointer deflects approximately as shown in Fig. 1.

Rub the PVC rod again and hold over the electroscope as shown in Fig. 1, but without touching it.

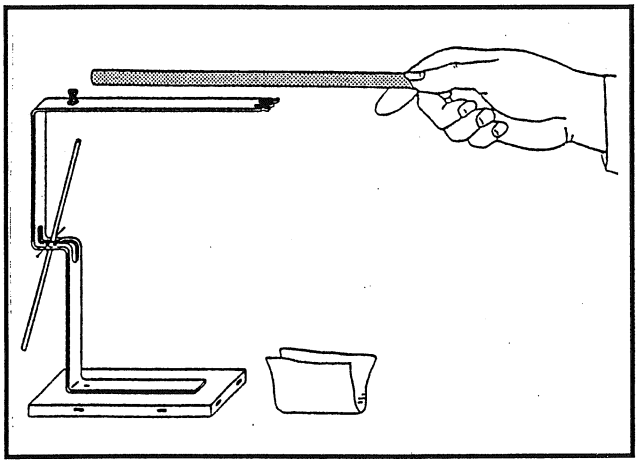


Fig. 1

Experiment 2:

Charge the acrylic glass rod by rubbing it with paper.

Hold the rod over the electroscope as shown in Fig. 1 without touching it.

Experiment 3:

Charge the acrylic glass rod by rubbing it with paper.

Brush the rod against the top of the electroscope until the pointer deflects as shown in Fig. 1.

Then rub the PVC rod powerfully with the paper once more and hold over the electroscope as shown in Fig. 2, but without touching the letter.

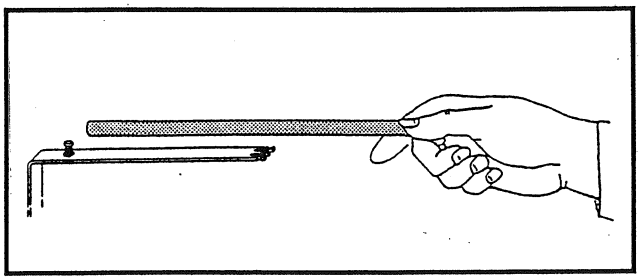


Fig. 2

Experiment 4:

Charge the PVC rod by rubbing it with paper.

Hold the rod over the electroscope as shown in Fig. 1, but do not touch it.

Observations and explanations:

Task:

How is it possible to see whether the electroscope has been charged with a PVC rod or acrylic glass rod rubbed with paper?

Teacher's sheet

Induction phenomena on an electroscope caused by friction rods

Experiment aim: The student should be able to use induction phenomena on an electroscope to distinguish between charge types.

Apparatus:

1	Electroscope S	540 08
1	Pair of friction rods made of acrylic glass and PVC	541 00
1	Sheet of rough paper	

Result:

The (incompletely) charged electroscope increases its pointer deflection if the rod which is brought close possesses the same charge polarity.

It reduces its deflection if the charges are different.

As a result of induction, additional charges are forced into the proximity of the pointer if the charges possess the same polarity, or charges are removed from the pointer surroundings if the charges are of opposing polarity. Greater or lesser electrostatic repellence results in a greater or lesser pointer deflection.

Using the incompletely charged electroscope, it is also possible to distinguish between charge polarities.

Task:

If the PVC rod which has been rubbed with paper is brought close to the electroscope and the pointer deflection increases, then the electroscope possesses the same charge as the PVC rod rubbed with paper; it has the same polarity. If the deflection is reduced, however, the electroscope is charged with opposing polarity (e.g. an acrylic glass rod was used previously for charging).

Students' sheet 1

Discharge of an induced charge on an electroscope

Task:

- Induce and discharge a charge on the electroscope using friction rods.
- Determine the polarity of the remaining charge.

Apparatus:

1 Electroscope S
1 Pair of friction rods made of acrylic glass and PVC

Friction material:

1 Sheet of rough paper

Method:

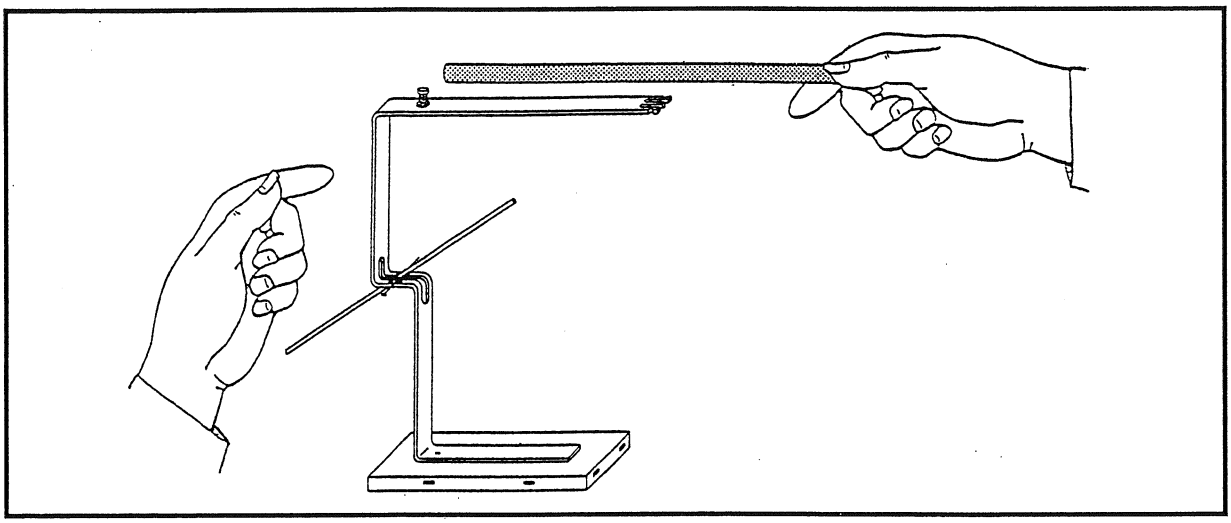


Fig. 1

1. Powerfully rub the PVC rod with paper.
2. Touch the electroscope with a finger.

   What effect does this have?
3. Hold the PVC rod close over the electroscope as shown in Fig. 1.
4. While holding the PVC rod like this, touch the housing of the electroscope with the other hand.

   What effect does this have?
5. Then remove the PVC rod.

   Watch the pointer!

   Powerfully rub the PVC rod with paper once more, hold over the electroscope again as shown in Fig. 1 and then remove again.

6. Powerfully rub the acrylic glass rod with paper and hold over the electroscope as shown in Fig. 1

Observations and explanations:

Task:

What is the effect of exchanging the PVC rod and acrylic glass rod in the experiment?

Teacher's sheet

Discharge of an induced charge on an electroscope

Experiment aim: The student should be able to correctly assess charge conditions before and after discharge of induced charges.

Apparatus:

1 Electroscope S 540 08
1 Pair of friction rods made of acrylic glass and PVC 541 00

Friction material:

1 Sheet of rough paper

Observations and explanations:

1. The PVC rod is (negatively) charged by rubbing with paper.

2. The electroscope is discharged by touching it with a finger.

3. The PVC rod held over the electroscope attracts unlike (positive) charges and repels like (negative) charges.

   The pointer deflects as a result of the excess of like (negative) charges in its proximity.

4. The charge excess in the proximity of the pointer is removed by touching the electroscope with a hand.

   The electroscope consequently possesses a charge excess with opposing polarity to the PVC rod.

   These charges are held by the charged PVC rod in the top part of the electroscope.

5. If the PVC rod is taken away, the pointer deflects, because charges of opposing polarity (positive) reach the pointer surroundings.

6. The acrylic glass rod is charged with an opposite charge to that of the PVC rod by rubbing with paper (positive).

   If the acrylic glass rod is held over the electroscope, the pointer deflection increases.

   Charges of the identically charged electroscope are forced into the proximity of the pointer.

Answer to task:

All polarities are reversed by exchanging the two friction rods. The experiment sequence and observable phenomena are the same.

Students' sheet

Induction phenomena on an electroscope caused by a foil

Task: Observe the pointer deflection of an electroscope when an electrostatically charged foil is brought close to it.

Apparatus:

1 Electroscope S
1 Acetate foil

Friction material:

1 Wool cloth

Method:

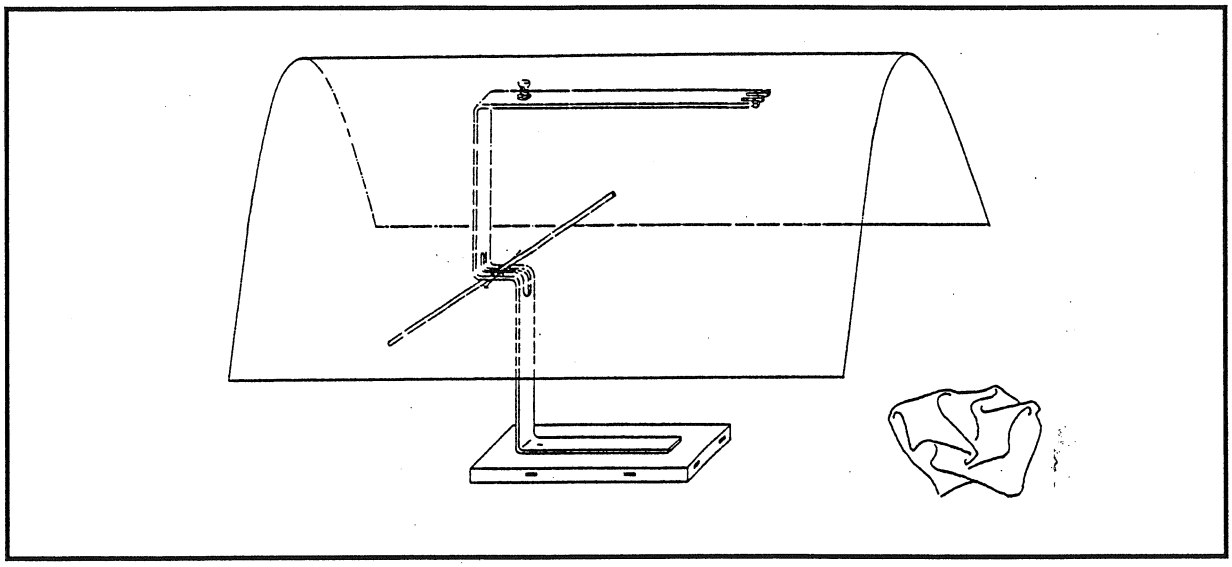


Fig. 1

Experiment part 1:

Discharge the electroscope by touching it with a finger.

Rub the acetate foil with the wool cloth, move close to the electroscope from above and place over the electroscope as shown in Fig. 1.

Experiment part 2:

Touch the metal housing of the electroscope at the base with a finger. Remove foil.

Observations and explanations:

Teacher's sheet

Induction phenomena on an electroscope caused by a foil

Experiment aim: The student should be able to explain

- why an electroscope is deflected when an electrostatically charged foil is brought close to it.
- why the pointer deflection increases when the housing is then touched.

Apparatus:

1 Electroscope S 540 08
1 Acetate foil . . . . . from 544 25

Friction material:

1 Wool cloth

Observations and explanations:

Experiment part 1:

When the foil is brought close, the electroscope pointer is clearly deflected.

Explanation: electric induction

Experiment part 2:

The pointer is deflected further when the electroscope is touched at the metal base.

Explanation:

Charges which possess the polarity of the foil are repelled as a result of high induction.

Charges with opposing polarity are located in the top part of the electroscope and charges with the same polarity in the bottom part.

There is a large excess of charges with like polarity in the metal base. If these charges are discharged, the electroscope charge with charges of opposing polarity is increased.

Students' sheet 1

Conductive bodies as charge stores

Task: Prove that conductive bodies like the induction plate, Faraday cup and electroscope act as a store for electric charges.

Apparatus:

1 Electroscope S
1 Faraday cup
1 Induction plate 40 x 80 mm with insulating handle
1 PVC friction rod
1 Acetate foil

Method:

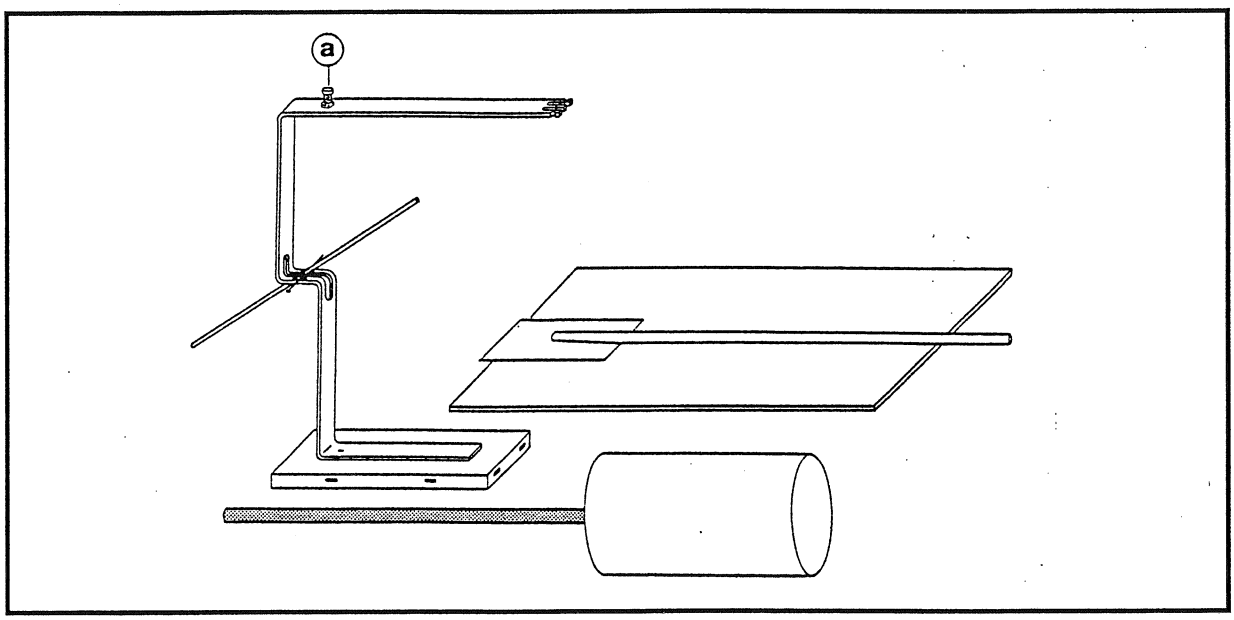


Fig. 1

Experiment 1:

Place the acetate foil on the table and rub with the induction plate.

Touch the electroscope with the plate.

Repeat this procedure several times.

Experiment 2:

Alternately touch point (a) on the electroscope and your own hand with the induction plate.

Experiment 3:

Repeat experiment 1, i.e. charge electroscope, and plug Faraday cup onto the PVC rod. Holding the rod, alternately touch point (a) on the electroscope and your own hand.

Observation and explanations:

Teacher's sheet 1

Conductive bodies as charge stores

Experiment aim: The student should be able to show with the electroscope that conductive bodies act as differently sized charge stores depending on their size and form.

Apparatus:

1	Electroscope S	540 08
1	Faraday cup	546 12
1	Induction plate 40 x 80 mm with insulating handle	542 51
1	PVC friction rod	451 00
1	Acetate foil	from 544 25

Observations and explanations:

Experiment 1:

Charges are transferred to the plate when the induction plate is rubbed on the acetate foil.

When the electroscope is touched, it accepts charges and the pointer deflects. Further charges are transferred if the procedure is repeated.

Result of experiment 1:

The induction plate and electroscope are charge stores.

Experiment 2:

It is possible to remove charges from the electroscope with the induction plate. The induction plate, which is used as a "charge spoon", is completely discharged by touching it with a hand. It can then accept charges from the electroscope again.

It is necessary to "spoon" approximately 20 times to discharge the highly charged electroscope.

Experiment 3:

Charges can also be transported with the Faraday cup. It is necessary to touch the electroscope only approximately 5 times with the discharged cup to discharge the highly charged electroscope.

Result of experiments 2 and 3:

The induction plate and Faraday cup act as charge stores of different sizes.

Note:

The storage capability of conductive bodies applies to both charge types.

This is demonstrated by experiments in which the electroscope is charged with charges of different polarity, e.g. with rods made of PVC and acrylic glass which have been rubbed with paper.

Additional experiment:

Charge the electroscope with different polarity.

Materials:

a) PVC rod rubbed on paper

b) Acrylic glass rod rubbed on paper

Location of charges on a Faraday cup

Task: Investigate the charge distribution on a Faraday cup.

Apparatus:

1 Faraday cup
1 Pair of friction rods made of PVC and acrylic glass
1 Stand base
1 Pair of stand feet
1 Stand rod, 25 cm
1 Induction plate 40 x 80 mm with insulating handle
1 Electroscope S

Friction material:

1 Sheet of rough paper

Set-up:

Plug the Faraday cup on the PVC rod and set up as shown in Fig. 1.

Then set up the electroscope at a distance of at least 50 cm away (➤ Fig. 2).

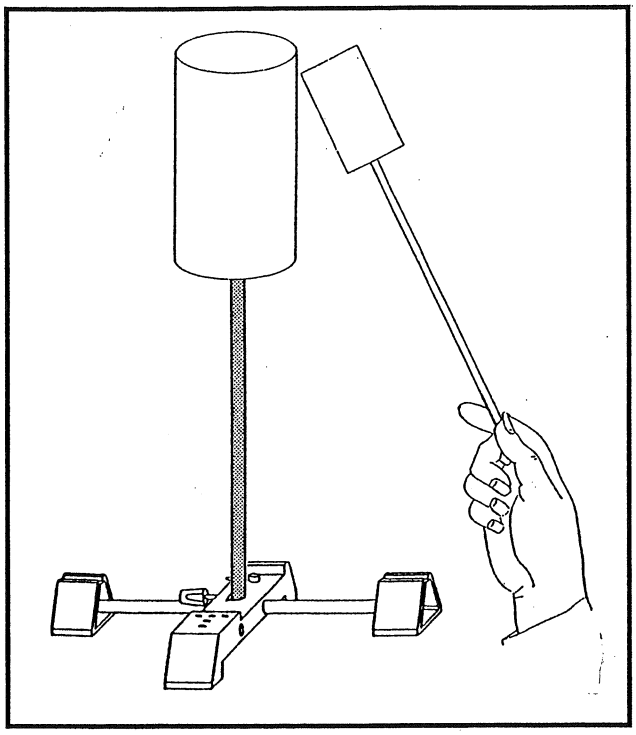


Fig. 1

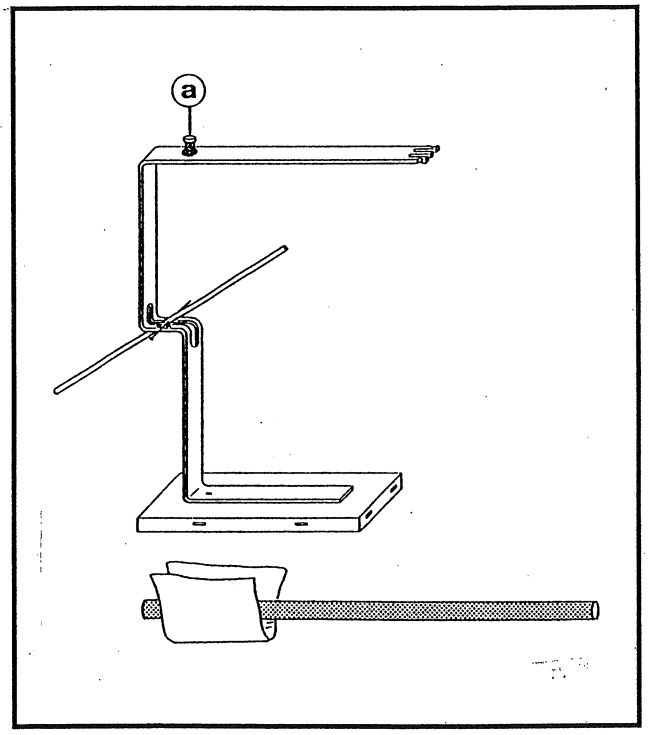


Fig. 2

Method:

In experiment parts 1.1 to 1.3, charges are transferred with the induction plate used as a charge spoon.

Question:

To what extent is charge transfer possible between the outside of the Faraday cup and the electroscope?

Experiment part 1.1:

Powerfully rub the acrylic glass rod with paper.

Charge the electroscope as highly as possible with it.

Using the induction plate, alternately touch the electroscope at point (a) and the outside of the Faraday cup until the pointer deflection no longer changes.

Experiment part 1.2:

Powerfully rub the acrylic glass rod and brush along the inner cup edge.

What is the effect of this?

Then alternately touch the outside of the Faraday cup and point (a) of the electroscope with the induction plate until the pointer deflection no longer changes.

Experiment part 1.3:

Touch the electroscope with a finger.

What happens as a result?

Again alternately touch the outside of the Faraday cup and point (a) on the electroscope with the induction plate.

Question:

Is it possible to transfer charges between the electroscope and the inside of the Faraday cup with the induction plate?

Experiment part 2.1:

Highly charge the electroscope and Faraday cup using the friction rod. First, alternately touch point (a) on the electroscope and the outside of the Faraday cup with the induction plate until the pointer position no longer changes.

Then choose the inside of the Faraday cup instead of the outside.

Important: Do not touch the edge of the Faraday cup with the induction plate or insulating handle during spooning.

Note:

To allow more convenient handling, the Faraday cup can also be held in the hand by the insulating handle. Keep away from the electroscope.

Experiment part 2.2:

Discharge the electroscope and charge the Faraday cup as highly as possible.

As before, touch point (a) and the inside of the cup alternately with the induction plate.

Observations and explanations:

Location of charges on a Faraday cup

Experiment aim: The student should learn that electric charges

- are located on the outside of a Faraday cup,
- located at the outside of the cup cannot be spooned unrestrictedly from and to other charge stores (e.g. electroscope),
- can always be discharged inside a Faraday cup
- cannot be removed from inside the Faraday cup

Apparatus:

1	Faraday cup	546 12
1	Pair of friction rods made of PVC and acrylic glass	541 00
1	Stand base	301 21
1	Pair of stand feet	301 23
1	Stand rod, 25 cm	301 26
1	Induction plate 40 x 80 mm with insulating handle	542 51
1	Electroscope S	540 08

Friction material:

1 Sheet of rough paper

Observations and explanations:

Experiment part 1:

The pointer deflection is first reduced and then remains constant.

Experiment part 1.2:

The Faraday cup is charged further in this experiment part.

Only charges from the outside of the cup can be transferred to the electroscope.

The pointer deflection first increases and then remains constant.

Experiment part 1.3:

The electroscope is discharged by touching it with a finger.

Charges are transferred to the electroscope from the outside of the cup. The pointer deflection increases and then remains constant again.

Explanation:

The Faraday cup, electroscope and induction plate are charge stores.

When two charge carriers touch, the charge carrier which is more highly charged gives off charge. No charges can be transferred after charge compensation.

The special characteristic of the Faraday cup is the distribution of its charges. These are displaced to the outside owing to repellence of like charges.

Experiment part 2.1:

While no charges can be transferred between the electroscope and outside of the Faraday cup, this is possible on the inside of the cup. However, only in one direction: from the electroscope to the Faraday cup.

Experiment part 2.2:

This experiment confirms the result of experiment part 2.1:

No charges can be removed from inside a Faraday cup.

Proof of charges on a Faraday cup

Task: Check the charge condition of a Faraday cup using a glow lamp.

Apparatus:

1 Electroscope S
1 Faraday cup
1 Pair of friction rods made of PVC and acrylic glass
1 Sheet of rough paper

Set-up:

➤ Fig. 1

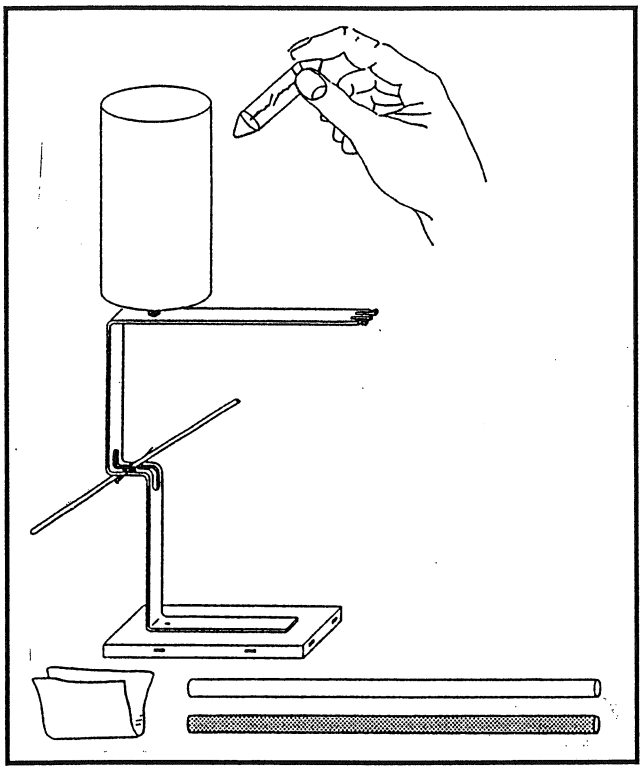


Fig. 1

Method:

Experiment 1:

Rub the PVC rod with paper.

Touch the Faraday cup with this until the electroscope pointer is deflected by a large amount.

Shield the light from outside slightly.

Hold the glow lamp as shown in the figure and touch the outside of the Faraday cup with it.

Experiment 2:

To discharge the Faraday cup, touch it from the outside with a finger.

Rub the acrylic glass rod with paper and charge the Faraday cup with it.

Verify the charge condition with the glow lamp.

Observations and evaluation:

Teacher's sheet

Proof of charges on a Faraday cup

Experiment aim: The student should be able to prove with a glow lamp that a Faraday cup can store charges with positive or negative polarity.

Apparatus:

1	Electroscope S	540 08
1	Faraday cup	546 12
1	Pair of friction rods made of PVC and acrylic glass	541 00
1	Sheet of rough paper	

Results:

Experiments 1 and 2:

The electroscope pointer is deflected owing to the outside of the Faraday cup being touched with a friction rod. It thus indicates that the system is charged.

The charge can be verified and its polarity established using the glow lamp.

Experiment 1:

When charging takes place with the friction rod made of PVC, the glow lamp electrode facing the cup lights up.

Experiment 2

When charging takes place with the friction rod made of acrylic glass, the glow lamp electrode facing away from the cup lights up.

Note:

For historical reasons, charges are called positive if the electrode facing away from the charges lights up. Otherwise, they are called negative.

Electrostatic forces on a Faraday cup

Task: Demonstrate the forces acting on a neutral body inside a charged Faraday cup and on its outer side.

Apparatus:

1 Faraday cup
1 Pair of friction rods made of PVC and acrylic glass
1 Stand base
1 Pair of stand feet
1 Stand rod, 25 cm
2 Strips of aluminium foil approx. 10 cm long, 3 mm wide
Clear adhesive tape, approx. 4 mm

Friction material:

1 Sheet of rough paper

Task: ➤ Fig. 1

Plug the Faraday cup onto the PVC rod and stand upright using the stand material.

Stick the two aluminium strips onto the outside and inside of the Faraday cup with clear adhesive tape (➤ Fig. 1/2).

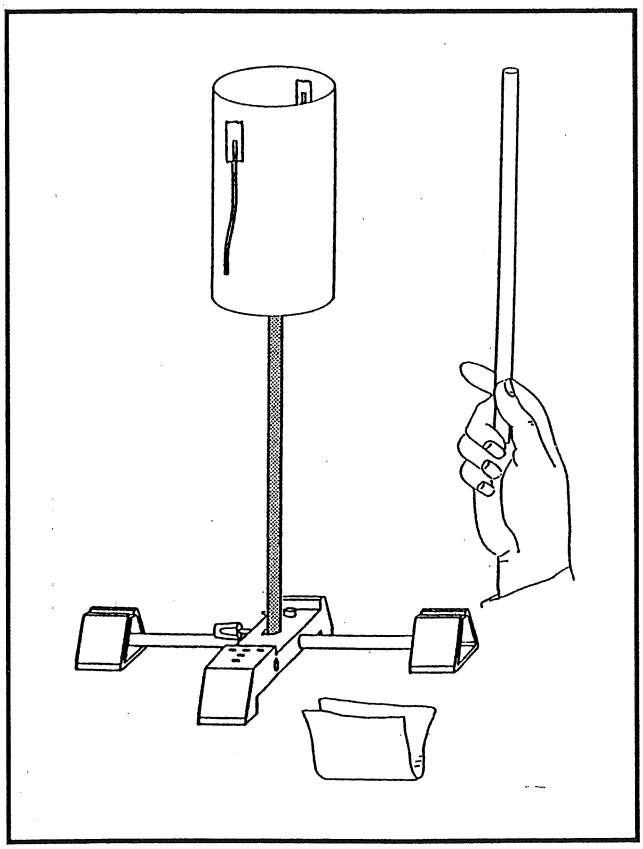


Fig. 1

Method:

Experiment 1:

Discharge the Faraday cup by touching it with a hand.

Rub the acrylic glass rod with paper.

Hold the rod in the Faraday cup.

Observe both aluminium strips.

Experiment 2: ➤ *Fig. 2*

Hold the rubbed acrylic glass rod next to the Faraday cup on the side facing away from the aluminium strip. Observe both aluminium strips.

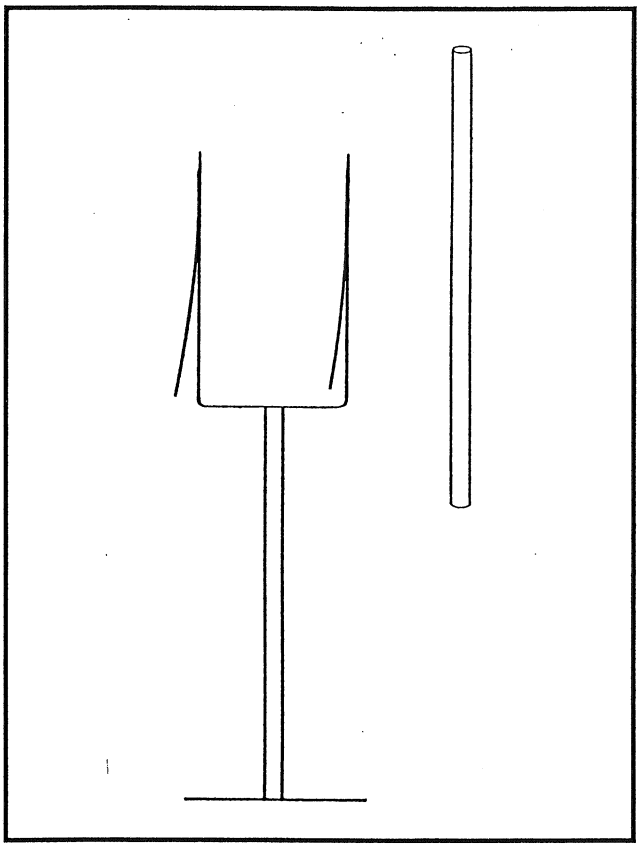


Fig. 2

Experiment 3:

Rub the acrylic glass rod which has been rubbed with paper on the cup edge.

What is the effect of this?

How do the aluminium strips behave?

Brief explanation of the observations:

Teacher's sheet 1

Electrostatic forces on a Faraday cup

Experiment aim: The student should be able to state and explain the forces acting on neutral bodies in the proximity of and inside a Faraday cup when the latter is exposed to electric charges.

Apparatus:

1	Faraday cup	546 12
1	Pair of friction rods made of PVC and acrylic glass	541 00
1	Stand base	301 21
1	Pair of stand feet	301 23
1	Stand rod, 25 cm	301 26
2	Strips of aluminium foil approx. 10 cm long, 3 mm wide	
	Clear adhesive tape, approx. 4 cm	

Friction material:

1 Sheet of rough paper

Observations and explanations:

Experiment 1:

The charged friction rod in the Faraday cup attracts the aluminium strip inside the cup: this is a result of forces acting owing to induction.

Charge separation is produced in the cup wall.

Charges with the polarity of the rod are displaced to the outer wall of the Faraday cup and the metal strip outside. Because it possesses the same charge polarity, the metal strip is repelled from the cup wall.

Experiment 2:

If the charged friction rod is held next to the uncharged Faraday cup, the aluminium strip inside the cup does not react at all. The cup shields the effects of external charges.

The metal strip outside curves away from the cup.

Reason:

Charging with identical polarity owing to charge separation as a result of induction.

Experiment 3:

When the charged friction rod is rubbed on the cup edge, part of its charge is transferred to the cup.

The aluminium strip inside the charged Faraday cup does not move.

The external metal strip is deflected away to a large extent.

Explanation:

The charges applied to the Faraday cup repel each other. The charge is located on the outside of the cup. Since the external metal strip accepts the same charge, it is violently repelled. Inside the cup, the cup charges acting on the neutral metal strip cancel each other out.

Electrostatic forces between a friction rod and pendulum

Task: Find out the forces which can occur between a friction rod and pendulum (metallized drinking straw).

Apparatus:

1 Electroscope S
1 Electrostatic pendulum pair
1 Pair of friction rods made of acrylic glass and PVC

Friction material:

1 Sheet of rough paper

Set-up:

➤ Fig. 1

Only one of the two pendulums is needed.

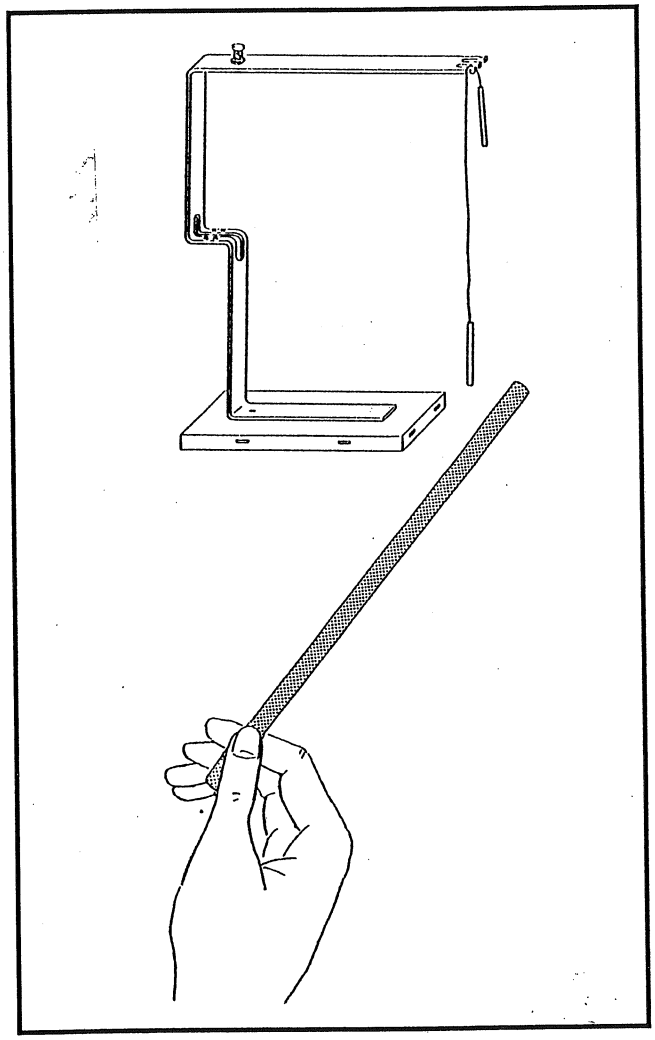


Fig. 1

Method:

Discharge the pendulum by touching it with a finger.

Experiment 1:

Rub the PVC rod with paper.

Slowly approach the neutral pendulum with the charged rod and then touch the pendulum.

Experiment 2:

Touch the pendulum with the charged PVC rod. Then slowly approach the rod to the pendulum again and touch the pendulum.

Observations and explanations:

Teacher's sheet

Electrostatic forces between a friction rod and pendulum

Experiment aim: The student should be able to demonstrate and explain the occurrence of attractive electrostatic forces between identically charged bodies.

Apparatus:

1	Electroscope S	540 08
1	Electrostatic pendulum pair	540 07
1	Pair of friction rods made of acrylic glass and PVC	541 00

Friction material:

1 Sheet of rough paper

Note:

It is also possible to work with the PVC rod instead of the acrylic glass rod.

Results:

Experiment 1:

The neutral pendulum is additionally attracted by the charged rod.

The pendulum receives a charge of opposing polarity caused by induction.

After touching with the friction rod, the pendulum is violently repelled by the friction rod. Like charges repel.

Experiment 2:

The identically charged pendulum is repelled as long as the rod is kept a certain distance away. As soon as the rod is brought any closer, the pendulum is attracted and then sticks to the friction rod.

Explanation:

Interplay of repellence by like charges and attraction by induced charge.

In the close area, the attractive force owing to induction is greater than the repellent force of like charges.

Students' sheet 1

Charge transport by a pendulum

Task: Show that charges can be transported in portions using a pendulum.

Apparatus:

1 Electroscope S
1 Pair of friction rods made of PVC and acrylic glass
1 Faraday cup
1 Electrostatic pendulum pair
1 Induction plate with insulating handle

Friction material:

1 Sheet of rough paper

Set-up:

➤ Fig. 1

Hang the pendulum pair over the edge of the Faraday cup so that one pendulum is inside and the other is outside.

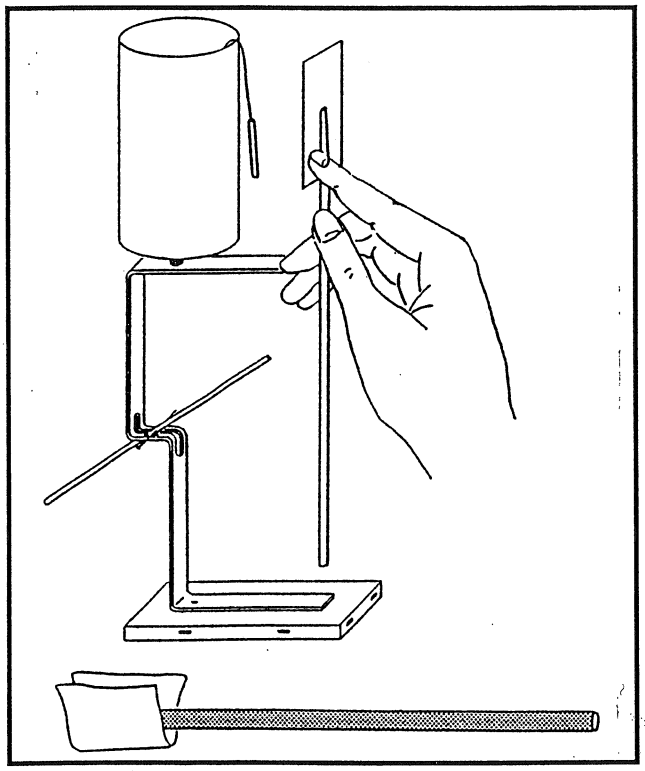


Fig. 1

Method:

Charge the electroscope and Faraday cup with a friction rod rubbed on paper until the pointer deflects.

Touch the induction plate with a finger and approach the pendulum slowly.

Observation and explanation:

Teacher's sheet

Charge transport by a pendulum

Experiment aim: The student should be able to explain independent charge transport by a pendulum.

Apparatus:

1	Electroscope S	540 08
1	Pair of friction rods made of PVC and acrylic glass	541 00
1	Faraday cup	546 12
1	Electrostatic pendulum pair	540 07
1	Induction plate with insulating handle	542 51

Friction material:

1 Sheet of rough paper

Observation:

The pendulum moves violently to and fro between the Faraday cup and induction plate (rough guide value: 50 times). The pointer deflection of the electroscope is reduced.

Explanation:

When the electrically neutral induction plate is brought close, charges of opposing polarity are induced there by the charged pendulum and Faraday cup.

The pendulum is attracted by the metal plate, touches the latter and gives off its charge.

The neutral pendulum now falls back to the cup and is also attracted owing to electric induction. When it touches the cup again, it takes up charge again.

If it is not resting on the outside of the cup, repellence by the cup predominates over attraction as a result of induction and the procedure is repeated.

Students' sheet 1

Charges on insulators

Task: Investigate the extent to which charges on an insulator are fixed.

Apparatus:

1 Electroscope S
1 Friction rod made of PVC

Friction material:

1 Sheet of rough paper

Method:

Discharge the electroscope by touching it with a finger.

Experiment:

Hold the rod in the center as shown in Fig. 1 and rub one end powerfully with paper.

Immediately after this, first touch point (a) on the electroscope with the non-rubbed end for several seconds and then with the rubbed end (➤ Fig. 2)

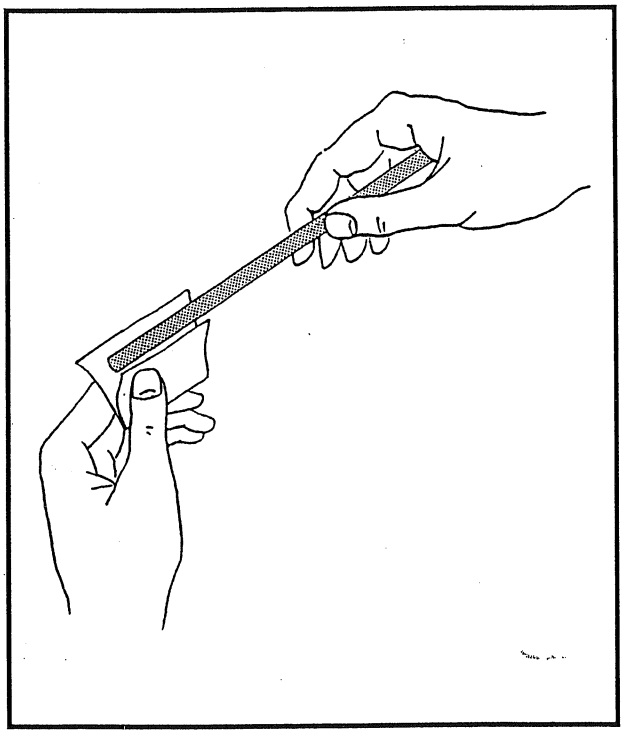


Fig. 1

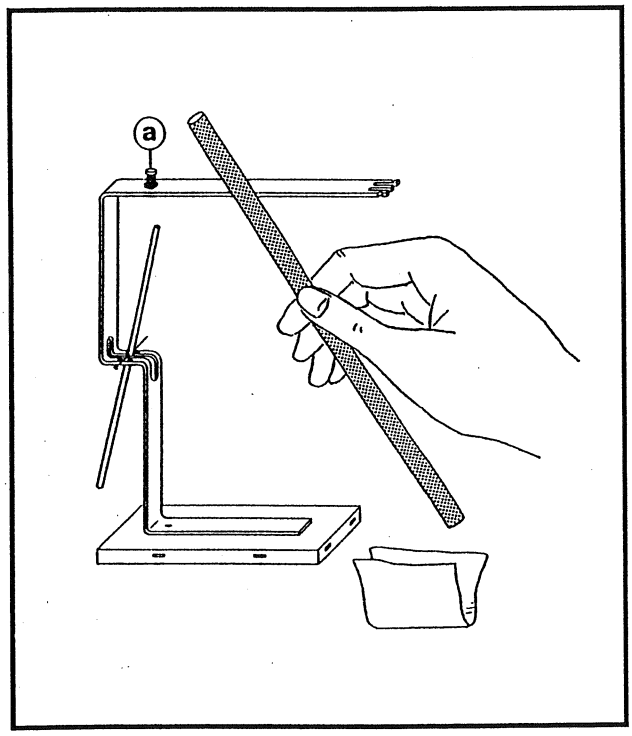


Fig. 2

Observation and explanation:

Teacher's sheet

Charges on insulators

Experiment aims: Awareness that charges on insulators are fixed.

Apparatus:

1 Electroscope S 540 08
1 Friction rod made of PVC . . . . . from 541 00

Friction material:

1 Sheet of rough paper

Result:

The pointer position of the electroscope does not change when touched with the non-rubbed rod end but changes when touched with the rubbed end. The respective indication remains constant when the electroscope is touched continuously.

The charges on insulators are fixed in one location; charge compensation does not occur.

Students' sheet 1

Proof of conductivity with a glow lamp

Task: Check whether a conductor and non-conductor can be distinguished using a glow lamp.

Apparatus:

1 Pair of friction rods made of PVC and acrylic glass
1 Induction plate, 40 x 80 mm with insulating handle
1 Glow lamp

Friction material:

1 Sheet of rough paper

Note on set-up:

Darken the room before the start of the experiment.

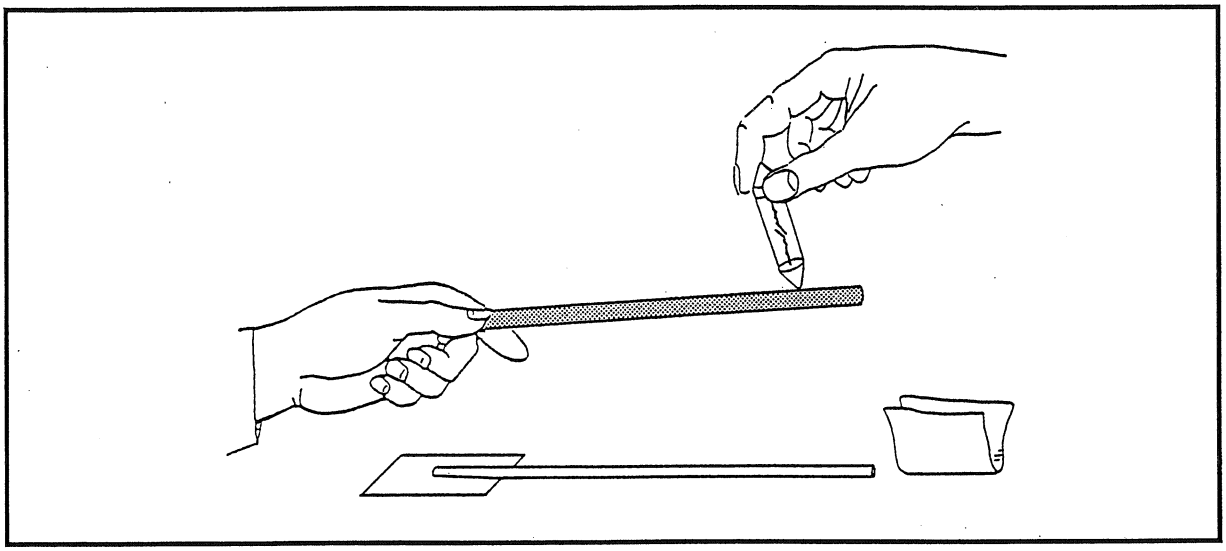


Fig. 1

Method:

Experiment part 1:

Powerfully rub the PVC rod over its whole length with the paper.

Touch the rod with the glow lamp at several points.

What do you observe?

Experiment part 2:

Powerfully rub the PVC rod on the paper. Then brush the induction plate along the PVC rod. Touch the induction plate with the glow lamp at several points.

What do you observe?

Experiment part 3:

Replace the PVC rod by the acrylic glass rod and repeat experiment part 1.

Experiment part 4:

Replace the PVC rod by the acrylic glass rod and repeat experiment part 2.

Experiment results

Summarize the results.

Teacher's sheet

Proof of conductivity with a glow lamp

Experiment aims: Understanding that

- charges can be removed only to a restricted extent at the contact points in plastics (PVC, acrylic glass) because the charges cannot move freely.
- the whole charge can be removed at any contact point in metal because charges in metals are freely mobile.

Apparatus:

1 Pair of friction rods made of PVC and acrylic glass 541 00
1 Induction plate, 40 x 80 mm with insulating handle 542 51
1 Glow lamp, double-ended . . . . . from 505 41

Friction material:

1 Sheet of rough paper

Experiment results:

Experiment parts 1 and 3:

When the rubbed plastic rods are touched at different points by the glow lamp, the glow lamp lights up each time.

Only the charge at the respective contact location is discharged. The charge at other points is preserved, i.e. charges cannot move freely in plastics.

Materials with this characteristic are called non-conductors.

Experiments parts 2 and 4:

When the same metal plate is touched by the glow lamp, the lamp lights up only the first time.

One contact of the metal with the glow lamp is therefore sufficient to discharge the whole charge.

Charges must therefore be freely mobile in metal.

Materials with this characteristic are called conductors.

Proof of conductivity with an electroscope

Task: Verify the conductivity of various bodies using an electroscope.

Apparatus:

1 Electroscope S
1 Pair of friction rods made of PVC and acrylic glass
1 Induction plate
1 Straw
1 Fishing line, approx. 20 cm
1 Glass beaker, approx. 200 ml water
1 Glow lamp

Friction materials:

1 Sheet of rough paper
1 Sheet of writing paper
1 Pencil

Set-up:

➤ Fig. 1

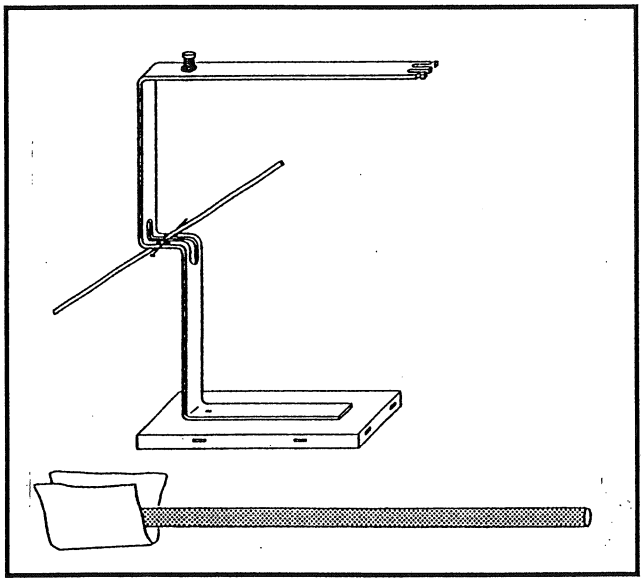


Fig. 1

Method:

Before each of the following experiments, charge the electroscope using a friction rod (made of PVC or acrylic glass) rubbed on paper.

Touch the charged electroscope at the top arm

1. with a hand
2. with the induction plate held by its handle

3. with the induction plate (metal) held in your hand (➤ Fig. 2)

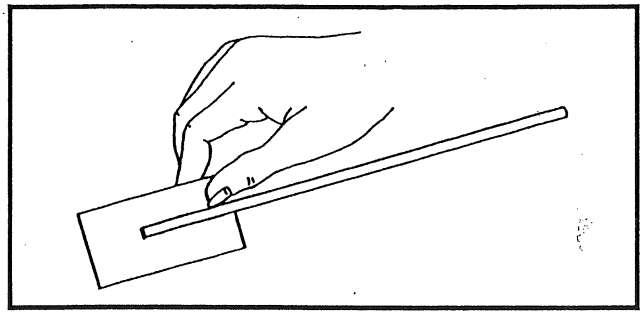


Fig. 2

4. via a friction rod (PVC, acrylic glass)
5. via dry fishing line
6. via wet fishing line (➤ Fig. 3)

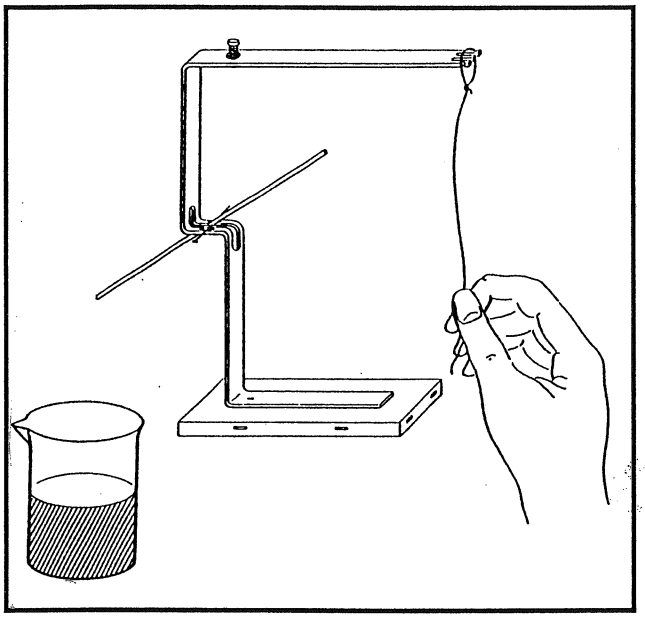


Fig. 3

7. via a sheet of paper with a lead line (graphite) (➤ Fig. 4)

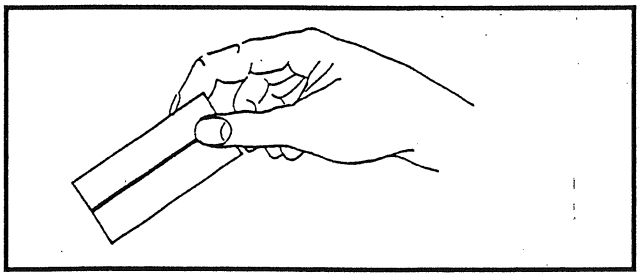


Fig. 4

8. via a long straw
9. via a short (held short) straw (➤ Fig. 5)

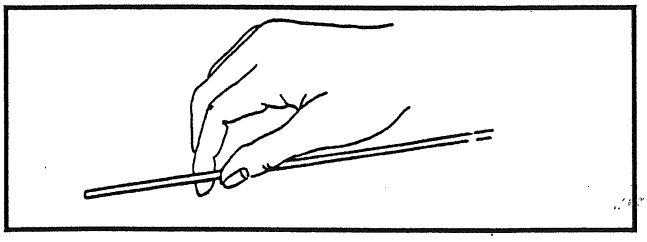


Fig. 5

10. via the glow lamp

    Hold by the metal cap (➤ Fig. 6)

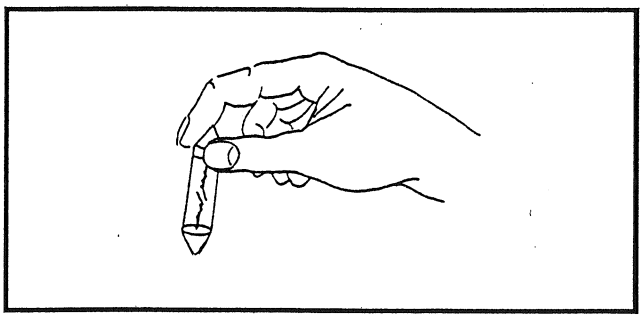


Fig. 6

Observations and explanations:

Teacher's sheet 1

Proof of conductivity with an electroscope

Experiment aims: Getting to know the electroscope as a sensitive instrument for assessment of the conductivity of materials.

Apparatus:

1	Electroscope S	540 08
1	Pair of friction rods made of PVC and acrylic glass	541 00
1	Induction plate	542 51
1	Straw from 540 08	
1	Fishing line, approx. 20 cm	309 48
1	Glass beaker, e.g. approx. 20 ml water	664 103
1	Glow lamp	505 41

Friction materials:

1 Sheet of rough paper
1 Sheet of writing paper
1 Pencil

Results:

1. The electroscope is discharged rapidly when touched by a hand. The human body is an electric conductor.

2. The pointer deflection is reduced slightly when the electroscope is touched with the induction plate held by the handle, but then remains constant.

Explanation:

The induction plate accepts a certain amount of the electroscope charge as a charge store.

The charges do not flow away via a handle made of PVC.

PVC is therefore a good insulator.

3. The charge flows away immediately when touched with the induction plate (metal) held in the hand. Metal is a very good conductor.

4. The electroscope does not lose its charge when touched with the friction rods.
PVC and acrylic glass are good insulators.

5./6. Dry fishing line is an insulator, but wet fishing line is not.

7. While dry paper is a good insulator, a pencil line on this represents a good conductor. The thicker, wider and shorter the line, the better it is as a conductor.

8./9. The straw also proves to be a conductor. The shorter it is, the better it conducts.

10. The distance between the two electrodes of the glow lamp can be bridged by charges. Since the glow lamp contains gas, this indicates that gases are also possible as conductors in principle.

Students' sheet 1

Influence of a flame on electrically charged bodies

Task: Investigate the effect of a non-smoking flame on electrically charged bodies.

Apparatus:

1 Electroscope S
1 Faraday cup
1 Pair of friction rods made of acrylic glass and PVC
1 Bunsen burner for butane gas
1 Butane gas cartridge

Friction material:

1 Sheet of rough paper

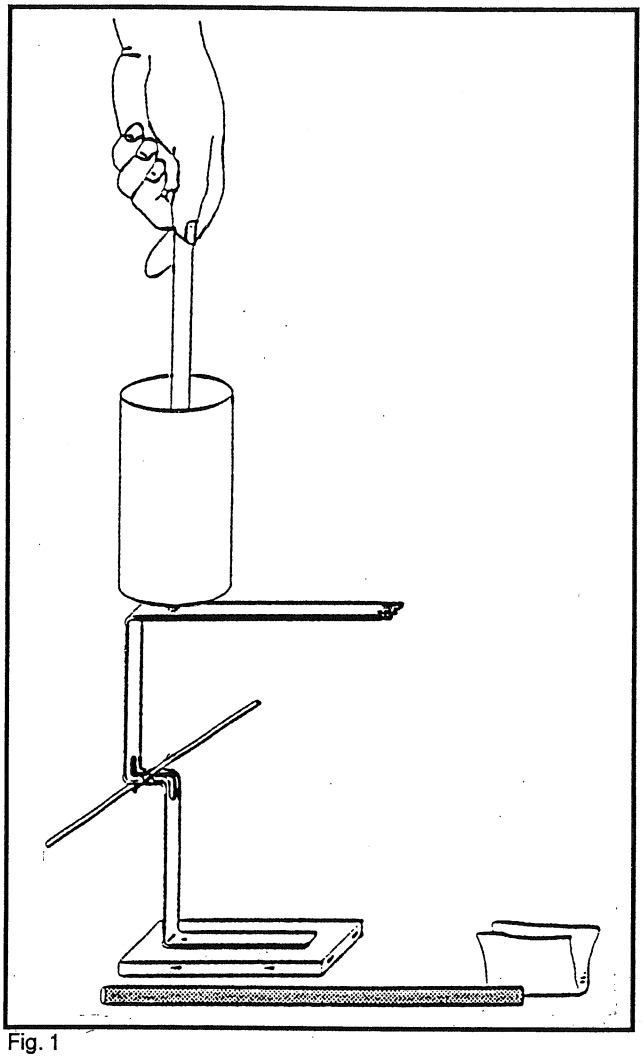


Fig. 1

Set-up:

Set up the butane gas burner as far as possible from the electroscope. Adjust the butane gas burner so that the flame is not luminous (does not smoke).

Method:

Rub the friction rods with paper and dip into the Faraday cup successively, but do not touch the cup.

Then move the whole length of the friction rods to and fro over the non-luminous flame of the burner several times in each case. Dip the rods into the Faraday cup again.

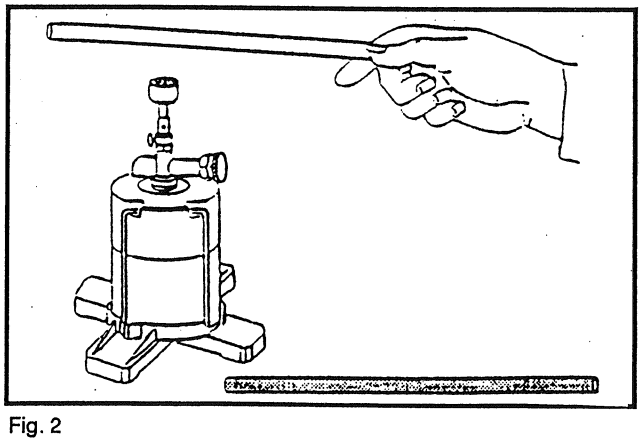


Fig. 2

Observation and explanation:

Teacher's sheet

Influence of a flame on electrically charged bodies

Experiment aim: Understanding that electrically charged bodies can be discharged by means of a non-smoking flame.

Apparatus:

1	Electroscope S	540 08
1	Faraday cup	546 12
1	Pair of friction rods made of acrylic glass and PVC	541 00
1	Bunsen burner for butane gas . . .	666 711
1	Butane gas cartridge from	666 712

Friction material:

1 Sheet of rough paper

Note:

The flame must not be luminous, i.e. contain soot particles. These are deposited on the rod and make the surface conductive.

Observations:

The friction rods rubbed on paper lead to a large electroscope pointer deflection in each case in the Faraday cup.

After movement over the non-luminous burner flame, the friction rods no longer produce a pointer deflection in the Faraday cup.

Result:

Using a flame, it is possible to discharge charged bodies.

Explanation:

The flame heats up the air to a great extent and makes it conductive (decomposed into charged particles - ions). The charges in the flame gases attract the charges on the friction rod to them and carry them away. They thus discharge the rods.

Students' sheet

Influencing the electroscope charge by means of a flame

Task: Investigate whether the charge of an electroscope is influenced by the proximity of a flame.

Apparatus:

1 Electroscope S
1 Friction rod made of PVC

Friction materials:

1 Sheet of rough paper
Matches

Set-up:

➤ Fig. 1

Charge the electroscope using the PVC rod rubbed with the paper.

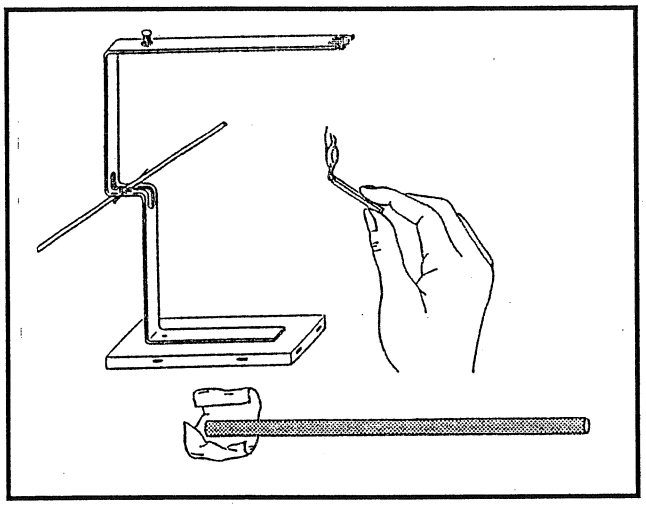


Fig. 1

Method:

Light the match and hold close to the charged electroscope as shown in Fig. 1.

Observation and explanation:

Teacher's sheet

Influencing the electroscope charge by means of a flame

Experiment aim: Understanding that a flame makes air conductive (ionized).

Apparatus:

1 Electroscope S 540 08
1 Friction made of PVC . . . . . from 541 00

Friction materials:

1 Sheet of rough paper
Matches

Result:

The match flame close to the electroscope leads to a rapid reduction in the pointer deflection.

The air becomes conductive (ionization of air) as a result of the flame.

The indication goes back to 0 owing to charge compensation with the environment.

Notes:

- Charged bodies - particularly non-conductors - can be freed of excessive charges using a flame. The flame should be non-smoking, i.e. non-luminous, for this purpose, otherwise a conductive soot layer will be deposited.
- Ionization of the air can be caused by radioactive radiation as well as by a flame.

Students' sheet 1

Point discharge

Task: Show the discharge of charges by electric sparks on the electroscope.

Apparatus:

1 Electroscope S
2 Pairs of friction rods made of PVC and acrylic glass
1 Faraday cup

Friction materials:

1 Sheet of rough paper

Set-up:

➤ Fig. 1

If possible, darken the room so that the electroscope can just still be seen well.

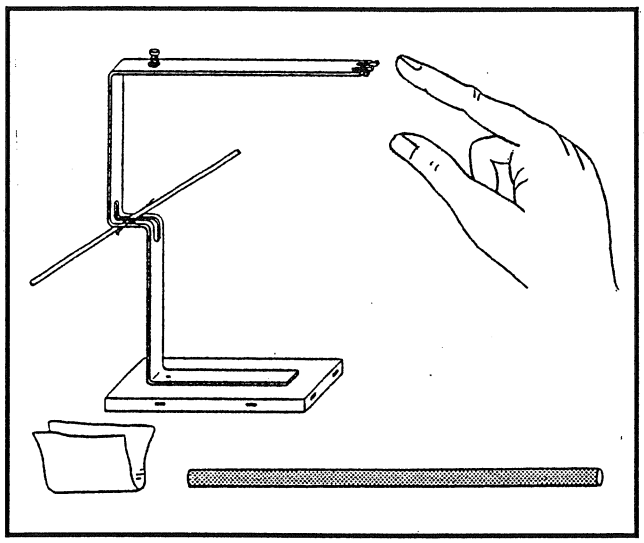


Fig. 1

Method:

Experiment 1:

Powerfully rub the PVC rod with paper. Using the charged friction rod, charge the electroscope.

Move your finger close to the outer edge of the electroscope as shown in Fig. 1, but do not touch!

Recharge the electroscope and move your finger up to other points on the electroscope.

Experiment 2:

As in experiment 1, but use the acrylic glass rod instead of the PVC rod.

Experiment 3:

Charge the electroscope using a friction rod (PVC or acrylic glass).

Plug the Faraday cup onto a PVC friction rod ➤ Fig. 2. Discharge the cup. How?

Instead of your finger as shown in Fig. 1, approach the electroscope with the Faraday cup held by the rod. Do not touch the electroscope.

How is it possible to check using the electroscope whether the Faraday cup contains charges after the experiment.

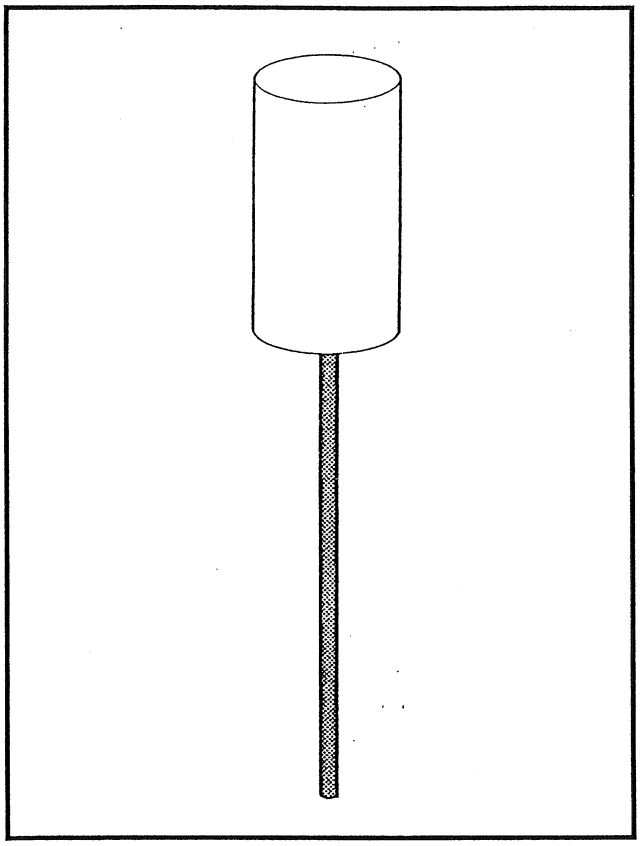


Fig. 6

Observations and explanations:

Teacher's sheet

Point discharges

Experiment aims: The student should know and be able to demonstrate

- that charged bodies can lose charges through the air in a spark
- that spark formation occurs predominantly at edges and points
- how the charge transported in the spark can be verified with an electroscope.

Apparatus:

1	Electroscope S	540 08
2	Pairs of friction rods made of PVC and acrylic glass	541 00
1	Faraday cup	546 12

Friction material:

1 Sheet of rough paper

Results:

Experiments 1 and 2:

When a finger is moved close so that it is approx. 2 mm away, a spark is heard to jump across and this is felt at the finger tip. The spark can be seen if the room has been sufficiently darkened.

At the same time, the pointer deflection decreases by a certain amount. The electroscope has given off part of its charge with the spark.

When the finger is moved close to different points on the electroscope, it is established that spark-over occurs much earlier at the corners, i.e. when the finger is further away (point effect).

Experiment 3:

The Faraday cup can be discharged extremely simply by touching it with a finger.

If there is only a small distance between the Faraday cup and the corner of the electroscope, a spark jumps across. The pointer deflection is clearly reduced.

The charge which is given off is stored in the Faraday cup.

Proof:

Discharge the electroscope with a finger and touch the Faraday cup at a corner, for example, with the electroscope. A clear pointer deflection is observed.

List of apparatus

SVN equipment set ESA1 (588 73)

1	Electroscope S	540 08
	with	
	1 set of 50 straws	200 67 491
	5 needles	241 24 104
1	Faraday cup	546 12
2	Polyethylene friction material	200 70 750
1	Electrostatic pendulum pair	200 67 941
1	Glow lamp, double-ended*	200 67 942
1	Pair of plastic clips	541 06
1	Insulating thread, 2 m	200 68 045
1	Dielectric set	544 25
	consisting of:	
	1 polystyrene sheet	
	5 acetate transparencies	200 70 750
1	Induction plate, 40 mm x 80 mm with insulating handle	541 51
2	Pairs of friction rods made of acrylic glass and PVC	541 00

Storage:

1	Preformed tray S	33-ESA1
	for storage of sets	
	L x W x H: 46.5 x 33.5 x 8.5 cm^3	

Additionally required apparatus for some experiments

	Stand base	301 21
1	Pair of stand feet	301 23
1	Stand rod, 25 cm	301 26
1	Pair of scissors	667 107
1	Fishing line, approx. 20 cm required	309 48
1	Beaker	664 103
1	Overflow vessel	362 04
1	Ruler or meter rule e.g.	311 04
1	Bunsen burner for butane gas	666 711
1	Butane gas cartridge	666 712
1	Wool cloth	
2	Sheets of rough paper, DIN A4	
1	Aluminium foil, 10 x 20 cm	
1	Clear adhesive tape, approx. 20 cm	
1	Box of matches	
	(required: 1 burning match)	
	Tap water	

* Cat. No. 505 41: set of 5 glow lamps, double-ended type