Leybold Physik
Physics
Physique

Mechanik
Mechanics
Mécanique

Forces – Simple machines

588 022
Students' work sheets
(Masters for copying)

Schülerversuche Naturwissenschaften
SVN
STM
Science Teaching Modules

STM-Physics
Mechanics
Forces/Simple machines

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General instructions on the use of STM work folders

The need for complete editorial revision of the literature in the STM series (Science Teaching modules series) containing descriptions of experiments for schools was an ideal opportunity to give the series a fresh, practical orientation:

The student's worksheets form the main focus of each work folder. These are laid out as a series of reference sheets, loose-leaf pages designed for use as master copies and capable of meeting the demands of a modern educational environment.

The associated teacher's workbook is an exact replica of the worksheets. In addition to defining the actual assignments, however, it also describes the object of each experiment and includes special hints and tips on each working step in the experiment, as well as additional information, calculated sample measurements and the answers to questions asked in the students' worksheets.

How the experiments are laid out:

The structure of the worksheets is essentially the same for all experimental topics. The basic information, such as the nature of the assignment itself, the list of apparatus required, setup diagrams etc. always appear in the same place and in the same order. For additional convenience, however, the experiments are also divided up into a series of consecutively numbered working steps. Diagrams and illustrations are also numbered consecutively. Any supplementary illustrations which appear in the teacher's notes are numbered according to the decimal classification system.

Symbols used:

The following symbols are used in the students' worksheets:

⚠ Caution! Hazardous for the experimenter or experimental apparatus.
Follow working instructions exactly.

▶ Refer to another point.

About the apparatus:

To familiarise students with the equipment they will be using, the worksheets are preceded by a detailed section describing the various pieces of apparatus.

In addition to the list of apparatus and other aids which appears before each experiment (complete with catalogue numbers in the teacher's workbook), you will also find a complete list of all the apparatus used at the end of the book (after the reference sheets), showing all the apparatus and other equipment required for the particular subject area under examination.

Each folder also contains a constantly updated list of the entire range of STM literature.

Preface

This book contains introductory descriptions of experiments for discovering the basic principles of mechanics, taken from the STM series (Science Teaching Modules). This textbook in particular focuses on topics coming under the general headings of "Forces" and "Simple machines".

All these experiments can be performed using apparatus from the sets BMC1 (Basic Mechanics and Thermodynamics 1), MEC1 (Mechanics 1) plus some additional apparatus.

Each experiment has been designed in such a way that it should be possible to complete the entire experiment in one double lesson. This includes the preparatory talk, handing out the apparatus, setting it up correctly, performing the actual experiment and writing it up.

You can save time by omitting certain steps or one or more parts of the experiment, and also by sharing the work involved in preparing test reports.

In this way, it should always be possible to adapt each experiment to the needs and abilities of a particular class.

The teacher's notes set out the objectives of each experiment, covering every topic.

A quick look at these summaries is sufficient to gain a general impression of the subject matter of the experiment in question.

About the apparatus

Setting up the stand

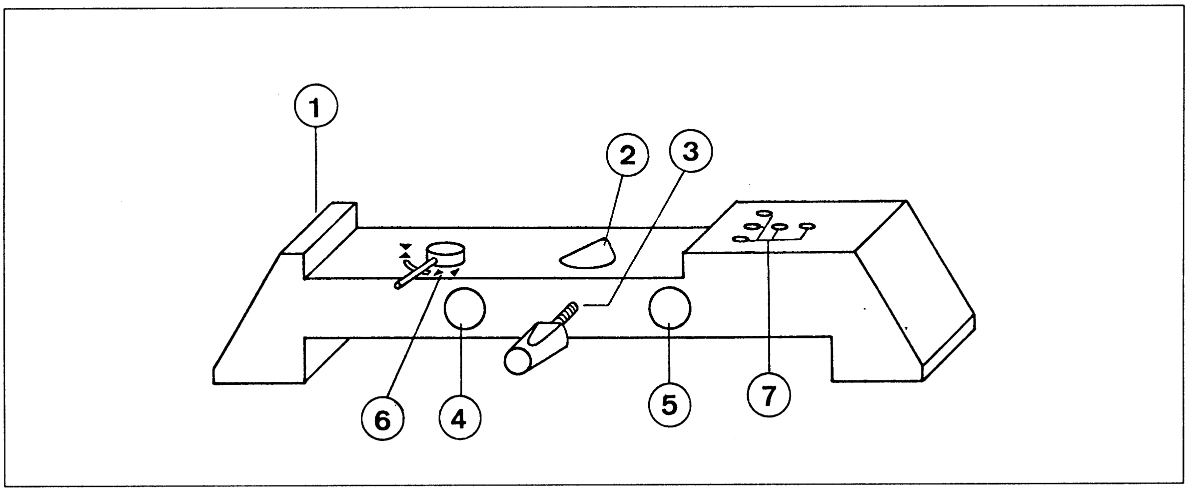


Fig. 1 Stand base (301 21)

Together with two 50 cm stand rods and one 25 cm stand rod, two stand bases **(1)** are the most important components in the various stand setups required for experiments covering mechanics and heat. A stand rod can be clamped firmly in the central socket **(2)** using a screw **(3)**. Two horizontal sockets **(4)** and **(5)** also accept stand rods, meaning that it is easy to create a stable base. Socket **(4)** has a quick-fastening clamp **(6)** with a toggle.
▶ Figs. 2/3. The five other sockets **(7)** are used for holding or mounting various items of apparatus using 4 mm plug pins.

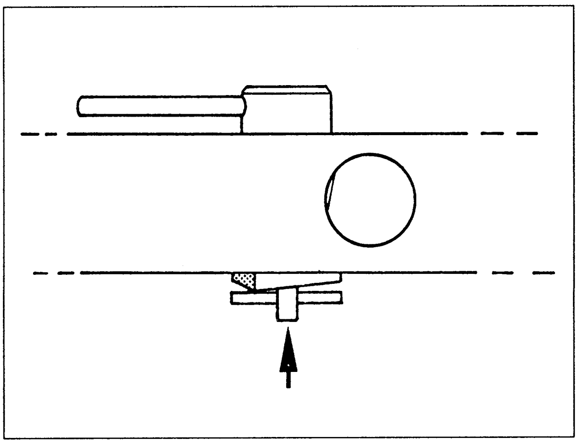


Fig. 2 Toggle on base of stand
▶ Arrow

Note on (6)

Socket **(4)**'s quick-fastening clamp with toggle may fit rather tightly at first. In this case, you will have to push the cone up slightly from underneath when you are inserting a stand rod.

The undersides of the stand bases are non-slip.

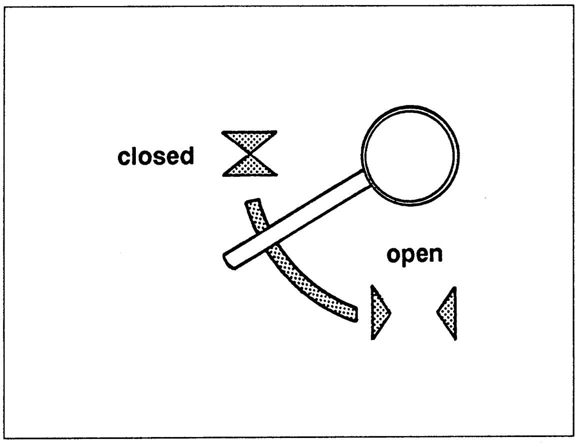


Fig. 3 Different toggle positions

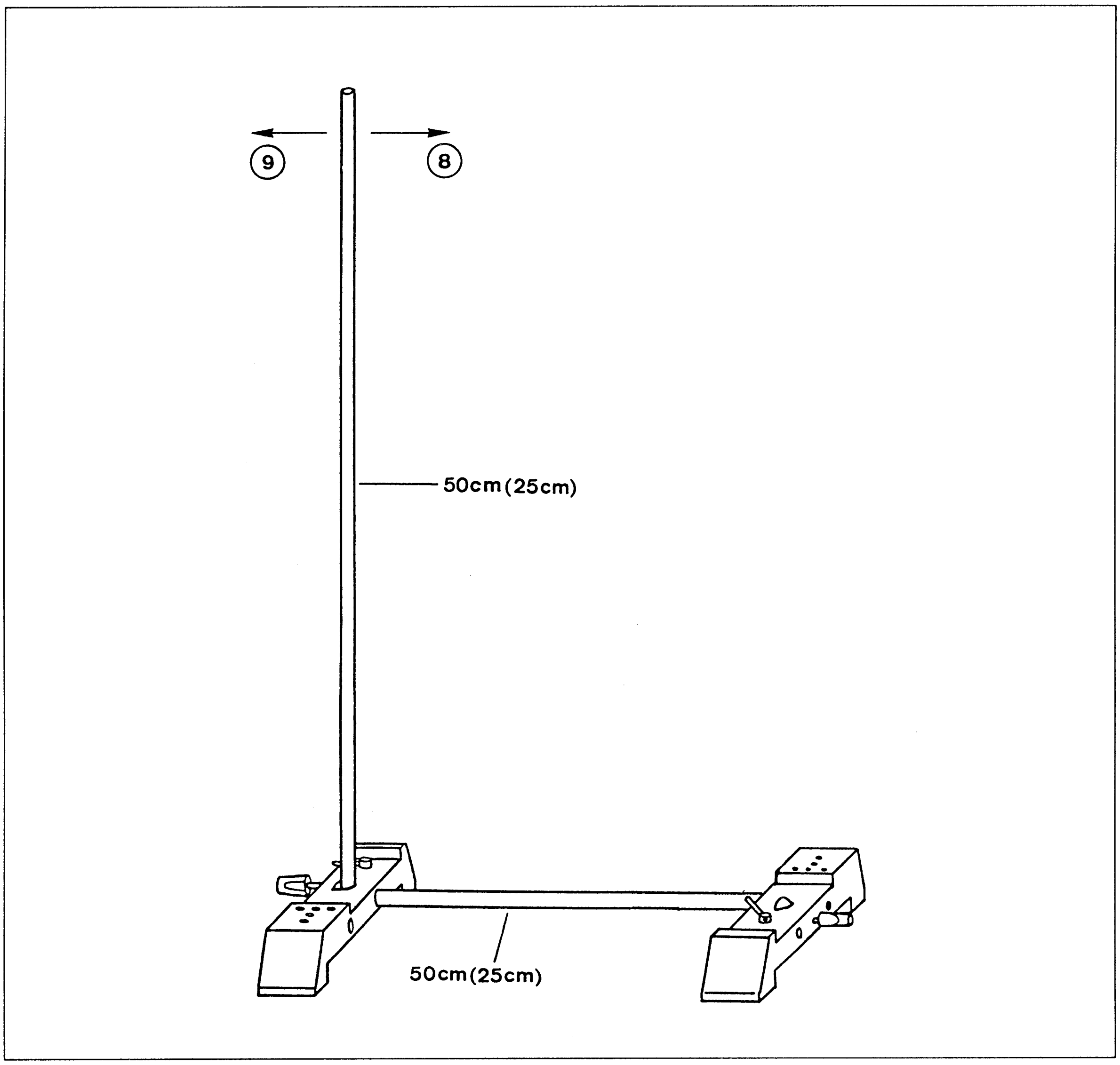


Fig. 4 Popular stand configuration

Fig. 4 shows a popular way of setting up a stand.
In which direction is the stand

a) most stable? ____________________

b) least stable? ____________________

Student's Sheet 3

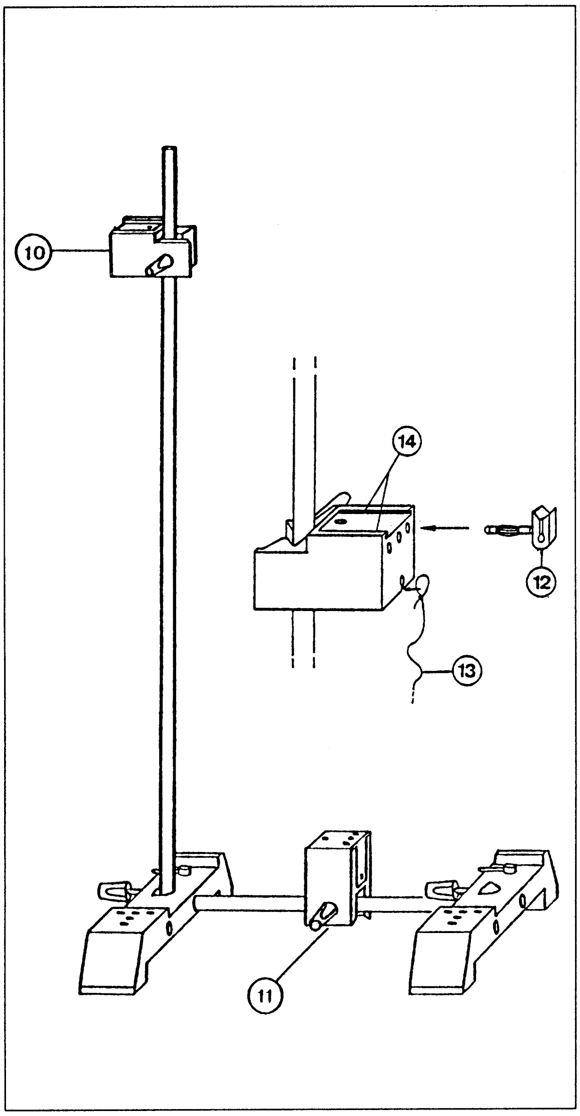


Fig. 5 Sleeve block

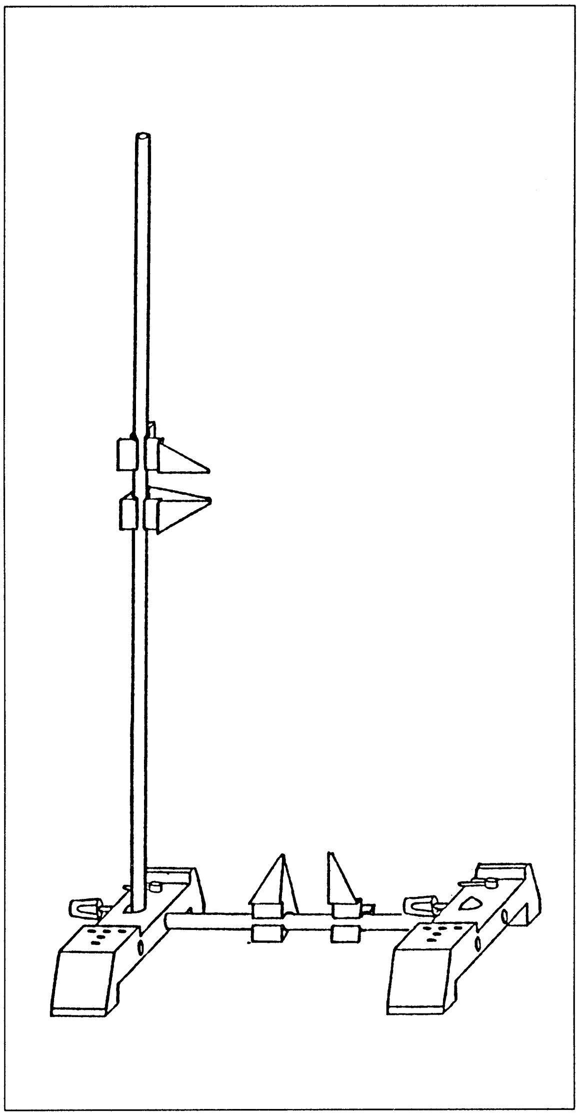


Fig. 6 Pointers

Sleeve block

You can attach the sleeve block to vertical **(10)** or horizontal **(11)** stand rods using the clamping screw.

The sleeve block has a total of eight sockets for holding plug-in experimental apparatus **(12)**, together with a cord holder **(13)** and a leaf spring holder **(14)**.

Pair of pointers

Pointers for marking starting positions, intermediate positions and final positions when you are comparing and measuring lengths are clamped to the stand rods. You can then rotate them or slide them along the rods.

Tip:

You will find it easier to slide the pointers along the rods until they are in the right position than to fit them directly into place on the rods.

Types of friction generated by solid bodies

Assignment: To compare frictional forces between solid bodies.

Apparatus:
2 pulley bridges
1 dynamometer, 1.5 N
1 aluminium cuboid
1 set of 6 weights
1 cord, 20 cm
1 sheet of paper, DIN A4
2 round pencils or felt-tip pens (or similar)
1 pair of scissors

Setup:

1. Lay out the apparatus for the experiment as shown in fig. 1.

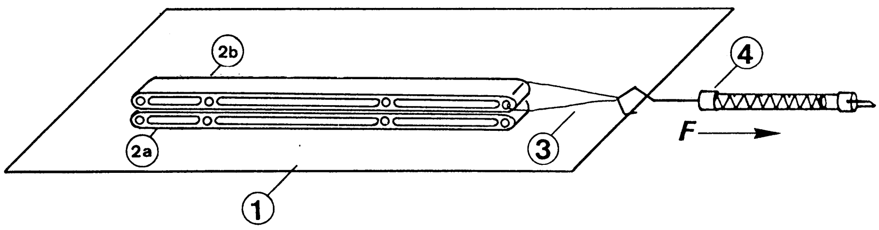


Fig. 1 Setup of experiment for investigating types of friction generated by solid bodies:
(1) Sheet of paper, DIN A4
(2a) Pulley bridge on **(1)**
(2b) Pulley bridge on **(2a)**
(3) Cord, 20 cm long, ends knotted
(4) Dynamometer, 1.5 N

Performing the experiment:

Experiment part 1 ▶ Fig. 1

2. Pull on the dynamometer with increasing force *F*.

Observations:

___

___

___

Student's Sheet 2

Experiment part 2 ▶ Fig. 2

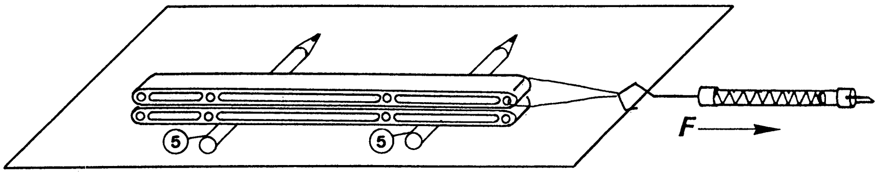


Fig. 2 Same setup as fig. 1, but on top of rollers: **(5)** round pencils or felt pens

3. Increase the force *F* as you did before, gradually.
   Observations:

   ____

   ____

   ____

Experiment part 3 ▶ Fig. 3

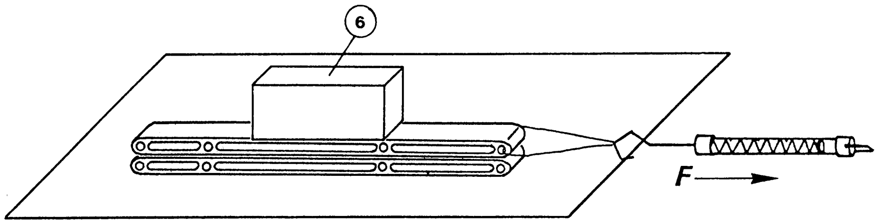


Fig. 3 Same setup as fig. 1, but with an aluminium cuboid **(6)** as an extra load

4. Increase the force *F* as you did before, slowly.
   Observations:

   ____

   ____

   ____

Experiment part 4 ▶ Fig. 4

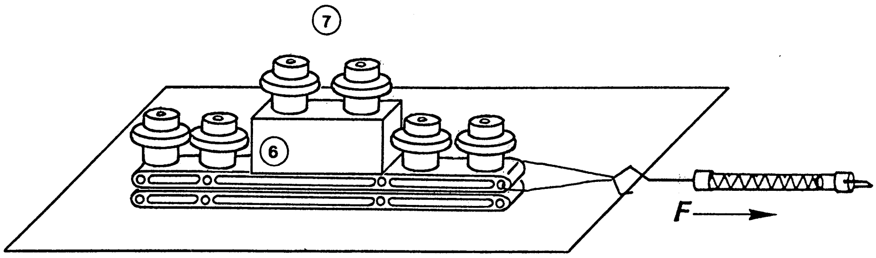


Fig. 4 Same setup as fig. 1, but with the cuboid **(6)** and 6 weights **(7)** as extra load.

5. Repeat experiment 3 several times, but with this greater load.
   Observations:

   ____

   ____

   ____

Evaluation:

6. Where friction occurs between solid bodies, it is possible to distinguish between three types of friction: static friction (stiction), sliding friction and rolling friction.
   In which parts of the experiment were you able to observe the following types of friction?
   a) Rolling friction:

   ____

   b) Static friction between plastic and paper:

   ____

   c) Static friction between plastic and plastic:

   ____

   d) Sliding friction between plastic and paper:

   ____

   e) Sliding friction between plastic and plastic:

   ____

Student's Sheet 4

7. Which type of friction between two materials generates the largest measured value?

___

___

8. Which type of friction between two materials generates the smallest measured value?

___

9. Name one industrial application of rolling friction:

___

10. Is there any way of reducing sliding friction, e.g. in car wheels?

___

___

Sliding friction (quantitative)

Assignment: To investigate the extent to which sliding friction depends on material, surface area and (force due to) weight.

Apparatus:
2 pulley bridges
1 dynamometer, 1.5 N
1 aluminium cuboid
1 set of 6 weights
1 cord, 20 cm
1 sheet of paper, DIN A4
1 pair of scissors

Setup:

1. Position the two pulley bridges next to one another as shown in fig. 1 and place the cuboid on top.
2. Make a loop out of the cord and tie it securely. Then place it round the cuboid.

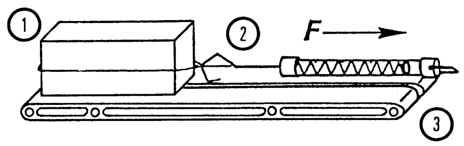


Fig. 1 Sliding friction:
(1) Aluminium cuboid (lying on its side)
(2) Cord, with both ends tied in a loop
(3) Two pulley bridges, positioned next to one another as a sliding support.

Student's Sheet 2

Performing the experiment:

Experiment part 1: sliding friction as a function of surface area

3. Pull the cuboid smoothly across the supports from left to right.
   Make a note of the force *F* required. ▶ Table
4. Place the cuboid upright. ▶ Fig. 2
   Repeat the experiment.
   Take a reading for *F* from the dynamometer. Enter it ▶ Table
5. Position one of the pulley bridges as shown in fig. 3. Pull the cuboid smoothly along on top of it from left to right. Take a reading for *F*. Enter the value ▶ Table.

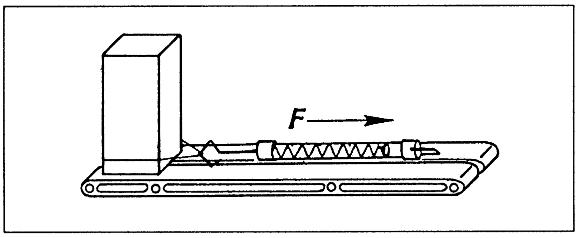


Fig. 2 Sliding friction where the surface area in contact has been reduced because aluminium cuboid is standing on end.

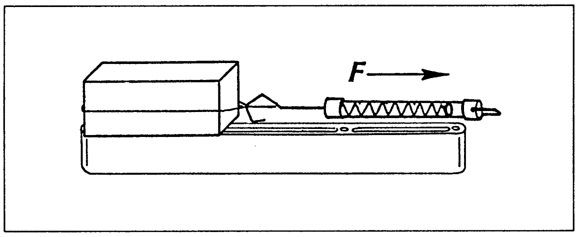


Fig. 3 Sliding friction where the surface area in contact has been reduced because pulley bridge acting as sliding support has been placed on its side.

Table 1

Material	Working step	Force of sliding friction $\frac{F}{N}$
Aluminium on plastic	3	
	4	
	5	
Plastic on paper	6	

Experiment part 2: sliding friction as a function of material

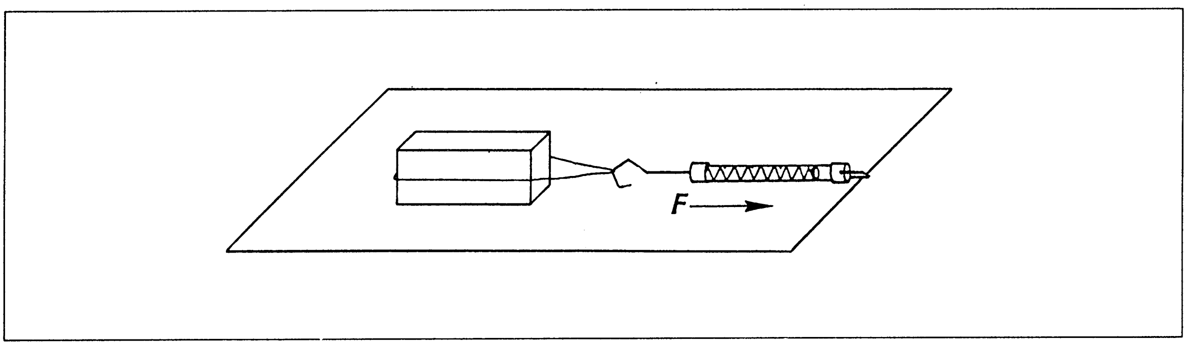


Fig. 4 Sliding friction with aluminium cuboid positioned on a sheet of paper

6. Place aluminium cuboid on the left-hand side of a sheet of paper. ▶ Fig. 4
   Move the cuboid smoothly over the paper by pulling on the dynamometer.
   Take a reading for the force *F*. Enter your reading ▶ Table.

Experiment part 3: sliding friction as a function of weight

7. Calculate the force due to weight exerted by the aluminium cuboid and weight.

   Cuboid: F =
   Weight: F =

8. Set up the experiment as shown in fig. 1.

   Place 0, 1, 2, 3, 4 weights on top of the block one after the other, measuring the sliding friction every time you add another weight.

   Enter the value ▶ Table 2.

Table 2

Material: Aluminium on plastic	
Force due to weight $\frac{F_N}{N}$	Force due to sliding friction $\frac{F}{N}$
1.0	
1.5	
2.0	
2.5	
3.0	

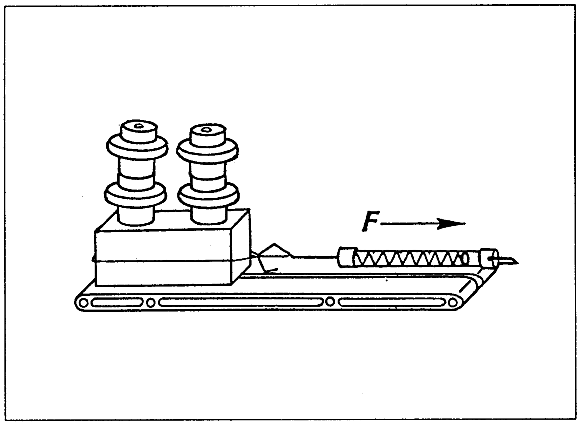
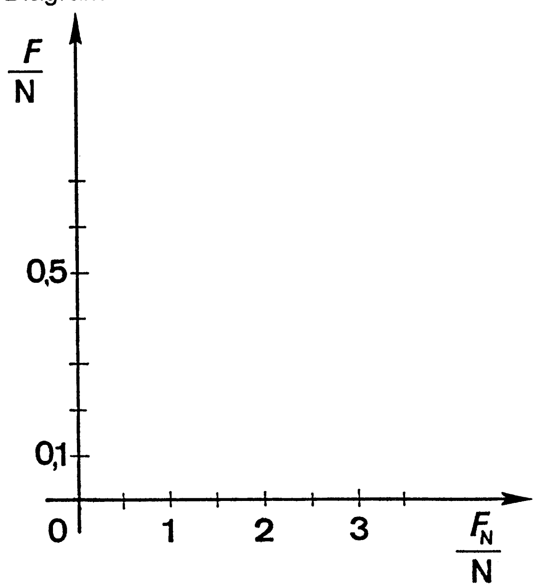


Fig. 5 Sliding friction, setup same as fig. 1. Aluminium cuboid loaded with weights

Evaluation:

9. Show the pairs of values for sliding friction F as a function of force due to weight F_N (perpendicular force), in the form of a graph.

Diagram



Student's Sheet 4

10. From the diagram, calculate the coefficient of friction $\mu = \frac{F}{F_N}$.

11. What do these experiments teach us about F, force due to sliding friction?
What does it depend on? – what does it not depend on?

Student's Sheet 1

Centre of gravity

Assignment: To calculate the centre of gravity of bodies with the help of a plumb line.

Apparatus:
2 stand bases
1 stand rod, 25 cm
1 stand rod, 50 cm
1 sleeve block
1 knockout spindle, 5.5 cm
1 pulley, 10 cm
1 pulley bridge
2 retaining clips
1 set of 6 weights
1 coupler plug
1 cord, 30 cm
1 paper clip (wire)
1 paper strip (self-adhesive, ca. 10 cm)

Setup:
1. Set up the apparatus as shown in fig. 1.
2. Push the large pulley onto the knockout spindle **(1)**.
3. Prepare a plumb line as shown in fig. 2 and hang it from the spindle.

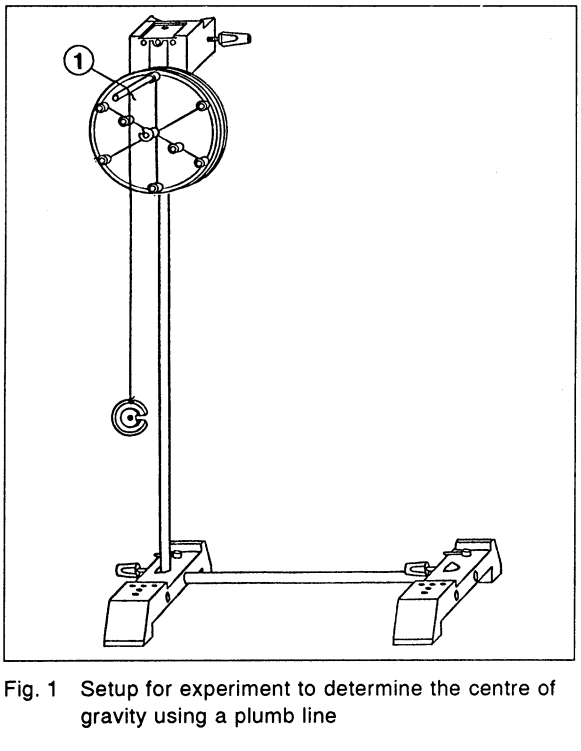


Fig. 1 Setup for experiment to determine the centre of gravity using a plumb line

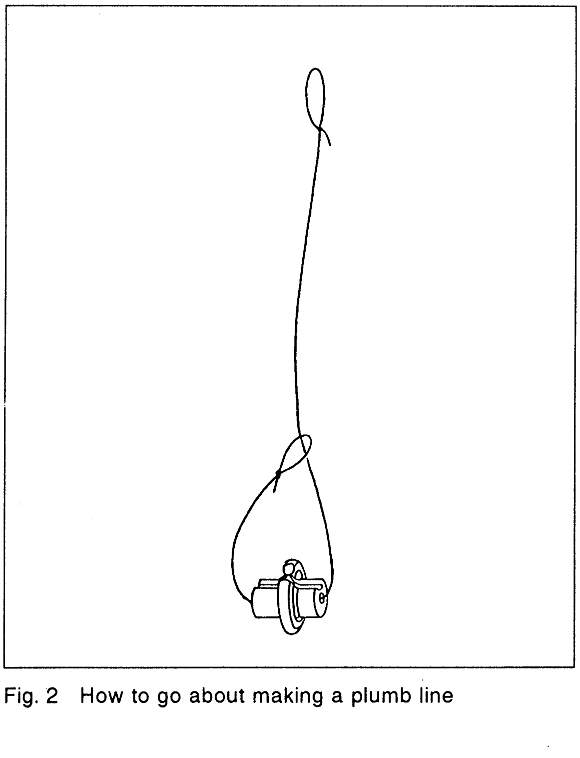


Fig. 2 How to go about making a plumb line

Performing the experiment:

Experiment part 1:
centre of gravity of the pulley

4. Hang the pulley from the spindle using various holes in the pulley.

Experiment part 2:
centre of gravity of a composite body

▶ Fig. 3 and fig. 4

5. Attach the pulley bridge to the big pulley using two retaining clips, as shown in fig. 4.
6. Push the entire assembly onto the spindle **(1)**, as shown in fig. 3.
7. Hang the plumb line **(2)** from **(1)** and attach the paper strip **(3)** to the big pulley as shown in fig. 3.
8. Make sure the cord **(2)** is hanging in such a way that it is positioned directly in front of the stand rod ▶ Fig. 3.
9. Pull the cord taut and press it against the stand rod.
10. Use a pencil to trace the length of the cord on the paper strip attached to the pulley.
11. Take the body off the spindle and then suspend it from the spindle again, one hole further to the right. Repeat steps 8 to 10.

Observations:

12. Suspend the body from each one of its other holes, measuring the position of the cord each time.

Observations:

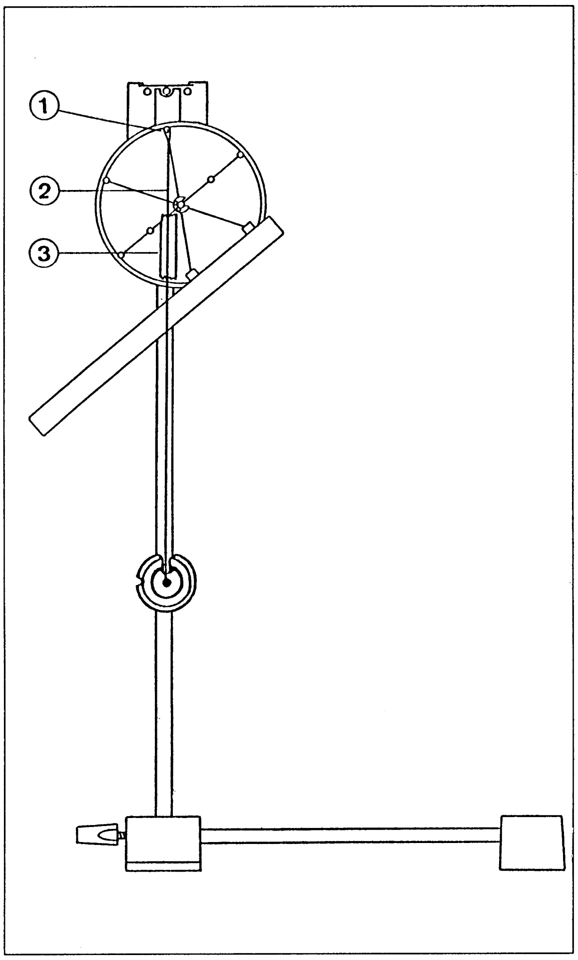


Fig. 3 Experimental setup as in fig. 1, with a composite body ▶ Fig. 4
(1) Spindle
(2) Cord
(3) Paper strip

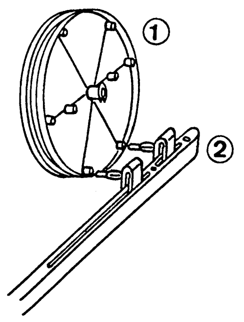


Fig. 4 Creating a body from a pulley **(1)** and a pulley bridge **(2)**, attached to **(1)** by two retaining clips.

Fig. 4.1 Result of steps 8 to 11 of the experiment

Student's Sheet 3

Experiment part 3:
keeping a body in equilibrium ▶ Fig. 5

13. Remove the body from the spindle **(1)** (in fig. 3) and plug the spindle into the hole in the top of the sleeve block. ▶ Fig. 5
14. Place the body on top of the spindle and move it around until it is perfectly balanced.
15. Examine the supporting point on the underside of the large pulley.

Observations:

____

____

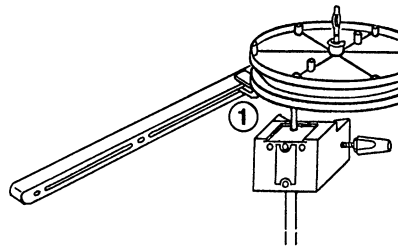


Fig. 5 Balancing the body composed of a pulley and pulley bridge on a spindle **(1)**.

Evaluation:

16. Where should you place the large pulley's axis of rotation so that it is in equilibrium in any position?

____

17. How do you explain the results of the experiment?

____

____

____

Student's Sheet 4

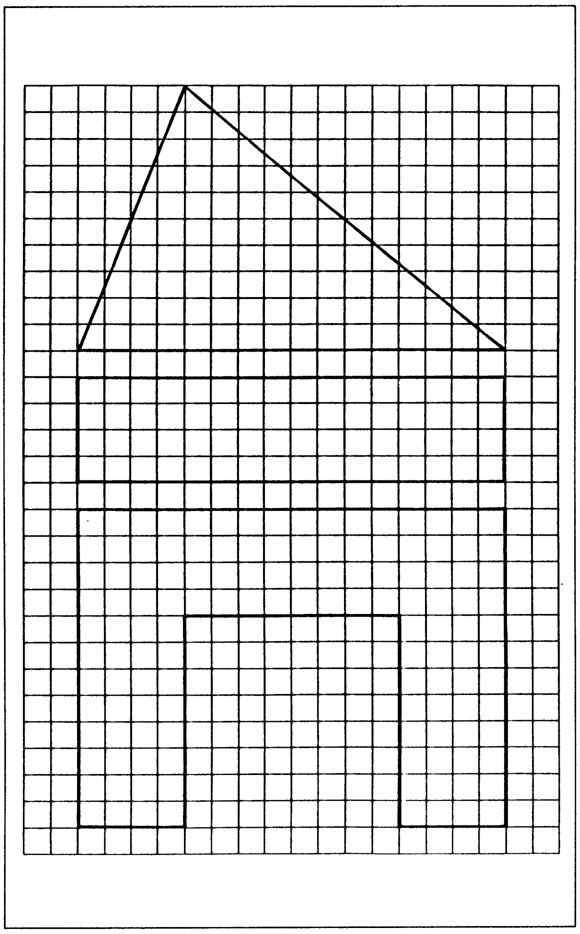


Fig. 6 Examples of regular bodies, which you can use to calculate centres of gravity

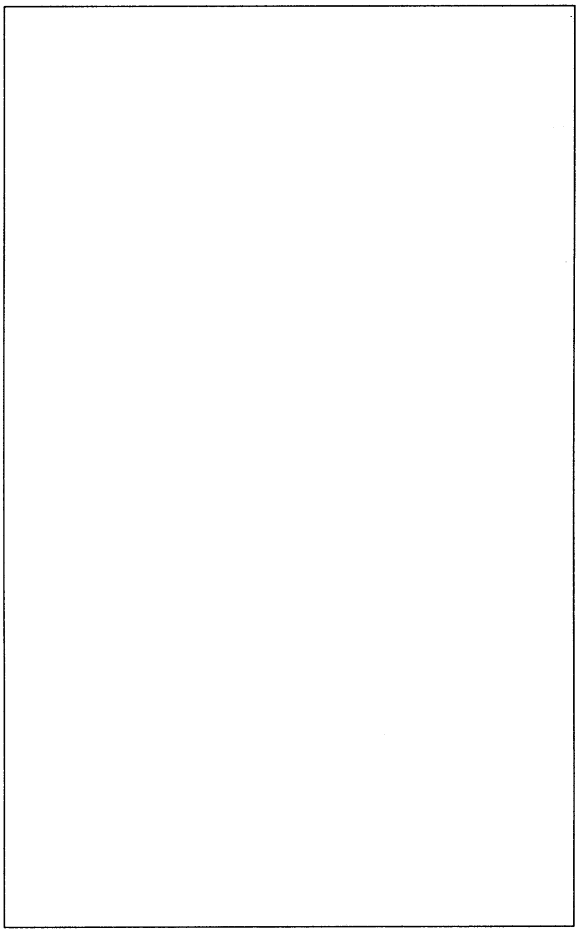


Fig. 6.1 Position of centre of gravity S of each of the bodies shown in fig. 6.

Stability

Assignment: To test the stability of a stand base.

Apparatus:
2 stand bases
1 stand rod, 25 cm
2 stand rods, 50 cm
1 dynamometer, 3 N
1 leaf spring
1 aluminium cuboid
1 tape measure

Setup:

1. Assemble the stand bases and stand rods as shown in fig. 1.

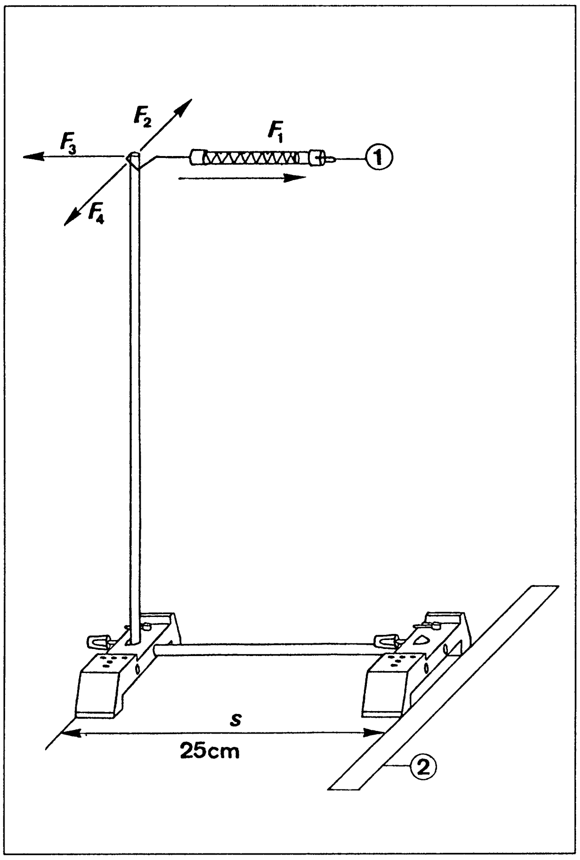


Fig. 1 Stand setup for testing stability
(1) Dynamometer, 3 N
(2) Leaf spring along the tipping edge

Student's Sheet 2

Performing the experiment:

Experiment part 1: testing the stability of the construction in fig. 1

2. Attach the 3 N dynamometer to the top end of the stand rod and pull in the directions shown.

   In each case, measure the force which must be applied in order to cause the structure to start to tip over.

   Enter your readings ▶ Table.

   Tip:

   If necessary, attach the leaf spring **(1)** to the appropriate tipping edge of the assembly in order to prevent it from sliding across the table.

Experiment part 2: testing the stability of the construction in fig. 2

3. Repeat the experiment (▶ 2.) using the heavier structure shown in fig. 2. Enter the values measured for the forces exerted ▶ Table.

Experiment part 3: testing the stability of the construction in fig. 3

4. How does the structure shown in fig. 3 differ from that in fig. 2?

____

5. Repeat the experiment using the assembly shown in fig. 3.

   Enter the values you measure for the forces exerted ▶ Table.

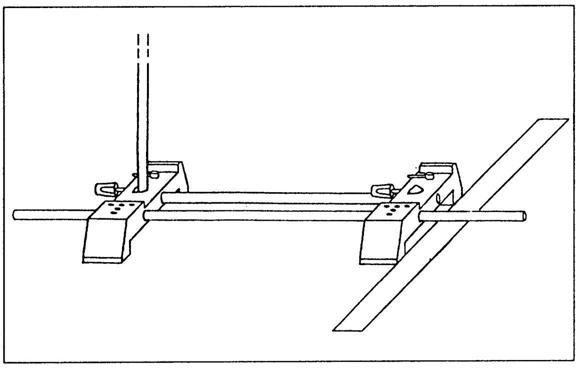


Fig. 2 Stand setup as in fig. 1 but with extra 50 cm stand rod

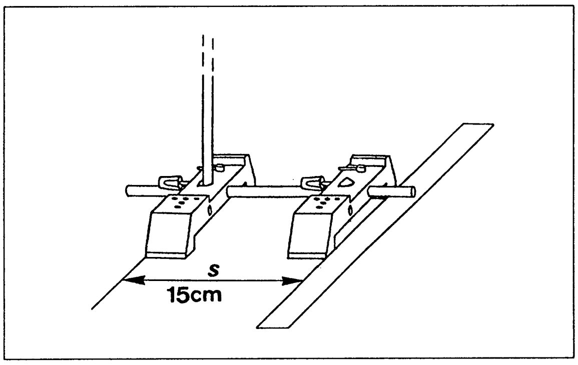


Fig. 3 Stand setup as in fig. 1 but with bases closer together

Table

Structure shown in	$\frac{F_1}{N}$	$\frac{F_2}{N}$	$\frac{F_3}{N}$	$\frac{F_4}{N}$
Fig. 1				
Fig. 2				
Fig. 3				

Experiment part 4:
tipping over an upright aluminium cuboid

6. Create an inclined plane by placing one end of the leaf spring **(2)** on the stand base **(1)**, as shown in fig. 4.

   Position the aluminium block **(3)** so it is standing upright on this surface.

   By moving the leaf spring, change the angle of inclination until the cuboid is just on the point of tipping over.

7. Leave the leaf spring in this position and lie the aluminium cuboid down next to it.

   What can you observe?

   ____

   ____

   ▶ Fig. 4.1

Experiment part 5:
tipping the horizontal aluminium cuboid

8. Repeat the preceding experiment with the aluminium cuboid in a horizontal position.

   ▶ Fig. 5.

   What do you observe?

   ____

   ____

   ____

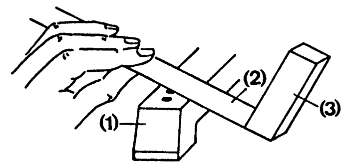


Fig. 4 Tipping experiment with a cuboid
(1) Stand base
(2) Leaf spring
(3) Aluminium block

Fig. 4.1 (1) Stand base
(2) Leaf spring, inclined so that the cuboid standing upright on it is just on the point of tipping over
(3) Aluminium cuboid

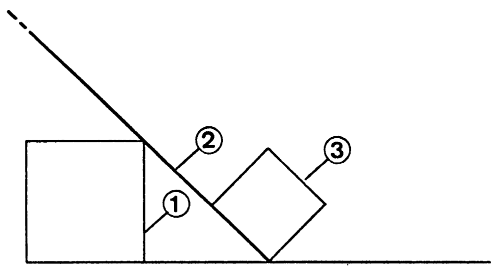


Fig. 5 Setup as in fig. 4 (schematically)
(1) Stand base
(2) Leaf spring
(3) Aluminium block

Fig. 5.1 Test setup as in fig. 4.1

Student's Sheet 4

Evaluation:

9. In how many directions could the stand setup in fig. 1 tip over?

10. In which direction is the stand assembly most likely to tip over?

11. In relation to which direction is the stand assembly (▶ fig. 1) at its most stable?

12. How can you increase a body's stability?
    Measures to take:

13. When does a body which is standing on its tipping edge fall over?
    How might you define the conditions for this event in terms of the body's centre of gravity?

Elongation of a helical spring (Hooke's Law)

Assignment: Determining the longitudinal deformation of a helical spring as a function of force.

Apparatus:

1 helical spring **(1)**, 1.5 cm ⌀
1 helical spring **(2)**, 2 cm ⌀
2 stand bases
1 stand rod, 25 cm
2 stand rod, 50 cm
1 sleeve block
1 knockout spindle, 5.5 cm
1 set of 6 weights
1 tape measure
1 leaf spring
1 paper strip (self-adhesive, ca. 2 x 20 cm)

Setup:

1. Assemble the stand bases and stand rods as shown in fig. 1.
2. Fix the paper strip to the leaf spring, about 10 cm away from the hole.
3. Plug the spindle into the sleeve block's top centre hole and suspend the leaf spring from it.
4. Hang the helical spring **(1)** from the spindle, in front of the leaf spring.
5. Mark the zero point (lower end of the unloaded spring) on the recording strip.

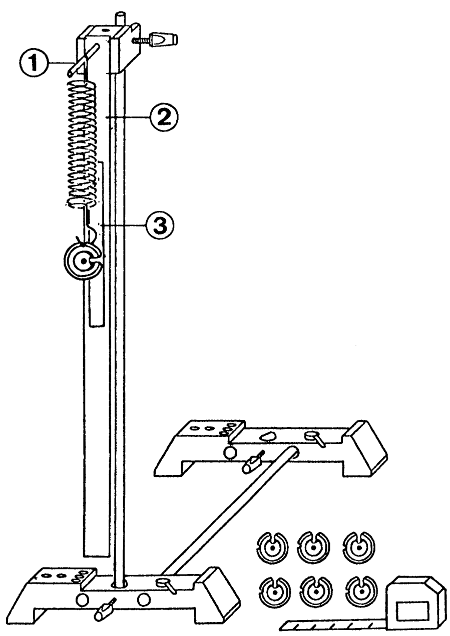


Fig. 1 Experimental setup for investigating the elongation of a helical spring:
(1) Knockout spindle
(2) Leaf spring
(3) Paper strip

Performing the experiment:

Experiment part 1:
helical spring (1), 1.5 cm ⌀

6. Attach a weight to the spring. (Force due to weight: $F = 0.5$ N)
7. Mark the position of the end of the extended spring on the paper strip.
8. Hang up to 6 weights from the spring, one after the other, recording the spring's elongation on the paper strip as you add each weight.

Experiment part 2: helical spring (2), 2 cm ⌀

9. Change helical spring **(1)** for helical spring **(2)**.
10. Remove the first paper strip (with the markings on it) and replace it with a new (unmarked) paper strip.
11. Record the elongation of helical spring **(2)** on the paper strip as you add first 1, then 2, 3 and 4 weights to it.

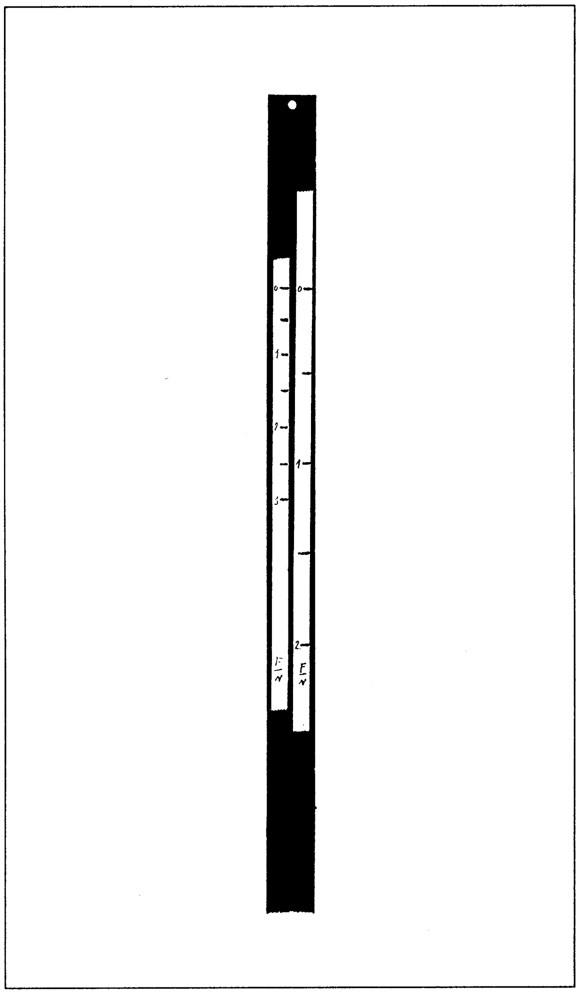


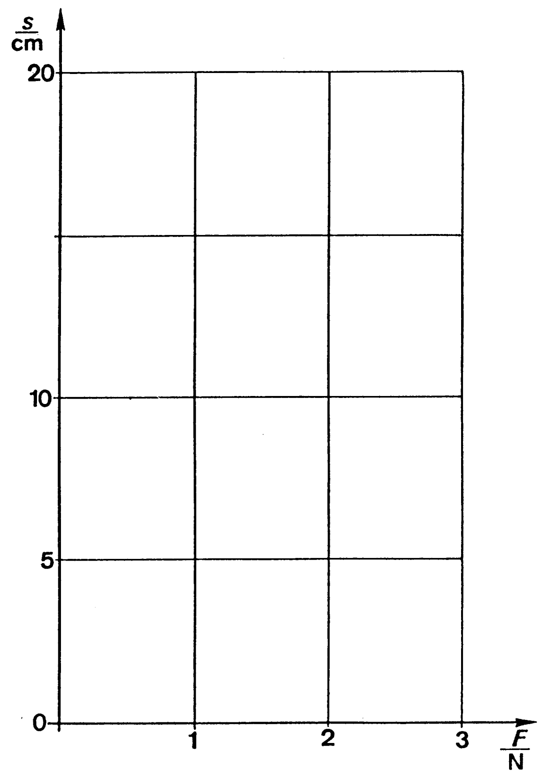
Fig. 2 Example of two test reports relating to the elongation of a helical spring

Student's Sheet 3

Evaluation:

12. Draw a graph showing the elongation of both helical springs as a function of force. To do this, copy the lengths marked on the paper strips directly onto the diagram.

Diagram



13. A simple law describes the elongation *S* of a helical spring by a given force *F* (*Hooke's* Law). How does it go?

____

14. The force required to elongate the helical spring by 1 cm is known as the spring constant *D*.

a) What is the unit used to measure *D*?

____

b) What is the value of *D* (the spring constant) for helical spring **(1)** (1.5 cm ⌀)?

▶ Diagram

____

c) What is the value of *D* (the spring constant) for helical spring **(2)** (2 cm ⌀)?

▶ Diagram

____

15. Helical springs are used in vehicle suspension. When is the spring constant *D* greater: when the suspension is soft or hard?

    The spring constant *D* is greater when the suspension is_______

Notes:

Robert Hooke,
English physicist, 1635 to 1703

Hooke's Law ceases to apply if the spring's elongation exceeds what is known as the proportional limit. In the next range, up to the "elastic limit", the extent to which it depends on force is more complicated. If the elastic limit is exceeded, deformations result. This means that the elongated spring does not return to its original length once the force is removed.

Student's Sheet 1

Elongation of a rubber ring

Assignment: To represent the longitudinal deformation of a rubber ring as a function of force, in the form of a graph.

Apparatus:
1 stand base
1 stand rod, 50 cm
1 sleeve block
1 knockout spindle, 5.5 cm
1 leaf spring
1 dynamometer, 3 N
1 rubber ring
1 paper strip (self-adhesive, 9 mm wide, 2 x 25 cm)

Setup:

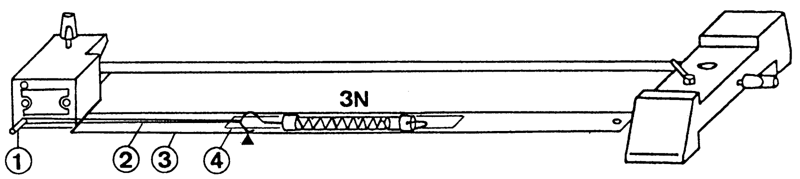


Fig. 1 Setup for experiment to investigate elongation of a rubber ring
(1) Spindle, **(2)** Rubber ring, **(3)** Leaf spring, **(4)** Paper strip

1. Set up the experimental apparatus as shown in fig. 1.
2. Push the leaf spring right up to the sleeve block on the left-hand side, as shown.
3. Fix two paper strips 25 cm long **(4)** to the leaf spring **(3)**, parallel to one another ▶ Fig. 1.

Performing the experiment:

4. Pull the dynamometer until you are exerting a force of ca. 1 N.
   Reduce the force of your pull until the dynamometer shows 0.
5. Mark the zero point on the paper strip nearest to you ▶ Arrow in fig. 1.
6. Then mark the paper in the same way while exerting a tractive force (pull) of 0.5 N, 1 N,1.5 N; 2 N; 2.5 N and 3 N respectively.
7. When you are exerting a pull of 3 N, move the dynamometer over to the paper strip which is furthest away from you and make a mark on this strip as well.
8. Now reduce the force of your pull in steps of 0.5 N, this time marking the corresponding position of the dynamometer on the second paper strip (the one furthest away), in the same way as you marked its positions on the first paper strip during the earlier part of the experiment.
9. Once you reach the end of the strip (furthest to the left), draw an arrow indicating the direction in which the values on the strip were measured.
10. Write the numbers 1, 2, 3 next to the marks for 1 N, 2 N, 3 N on each strip of paper, and then write $\frac{F}{N}$ at the other (right-hand) end of both strips.
11. Remove the paper strips from the leaf spring.

Fig. 1.1 Example of a record of test results

Evaluation:

Diagram

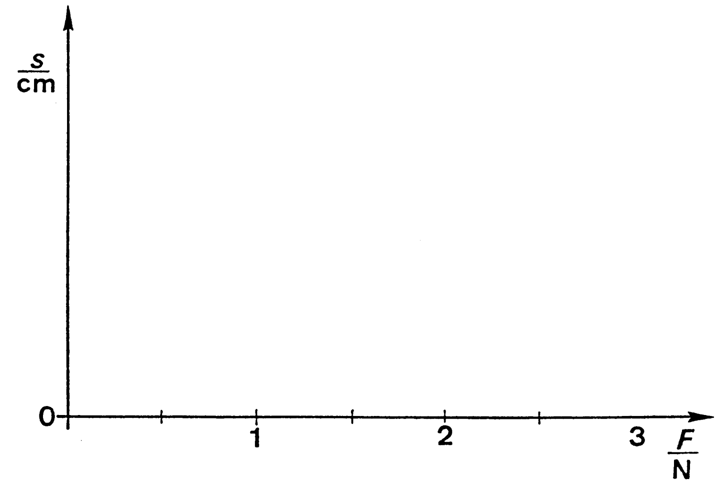


Fig. 2 Coordinate system
Length *s* of a rubber ring as a function of force *F*
o Measurements taken while ring extending in length
x Measurements taken while ring decreasing in length

12. Copy the values you recorded onto a coordinate system, as shown in fig. 2.
    Take careful note of the text (labels) on each axis!
13. How does rubber behave when it is stretched?

____

____

____

____

____

Hint:

The phenomenon whereby it is possible to observe a "lag" in deformations during stress reversal is described as *elastic hysteresis* (hysteresis from the Greek husteresis, coming too late).

A similar phenomenon can be observed during magnetic induction (known as *magnetic hyseteresis*)

Deflection of a leaf spring

Assignment: To determine a leaf spring's deflection as a function of its length and the force acting upon it.

Apparatus:

2 stand bases
1 stand rod, 25 cm
2 stand rods, 50 cm
1 universal socket
1 leaf spring
1 metal plate
1 pair of pointers (of which 1 required)
1 tape measure
1 set of 6 weights
1 cord, ca. 20 cm long

Student's Sheet 2

Setup:

1. Fig. 1 shows how to set up the apparatus for this experiment. Assemble the apparatus as shown, but do not attach the weight immediately.
2. Use the metal plate to clamp the leaf spring in position.
3. Use the pointer to indicate the zero position of the unloaded leaf spring ▶ Fig. 2.

   Do not change the position of the pointer once you have moved it to the relevant position.
4. Attach the weight to the end of the leaf spring ▶ Fig. 3.

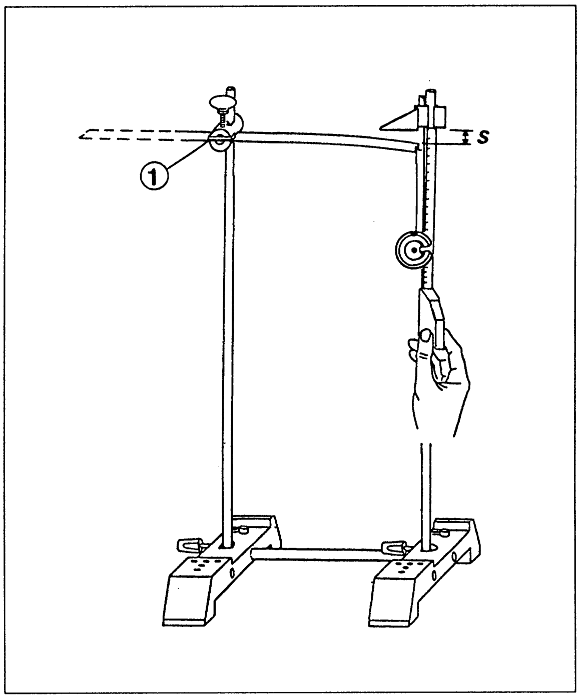


Fig. 1 Setup for testing a leaf spring's deflection

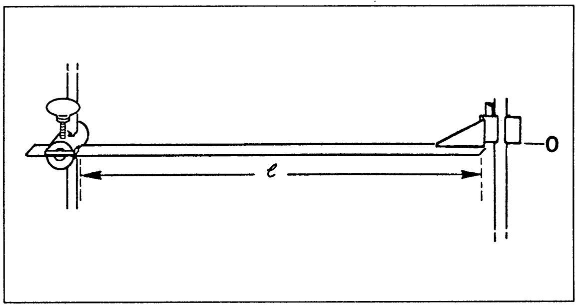


Fig. 2 Setting the pointer to the unloaded leaf spring's starting (zero) position

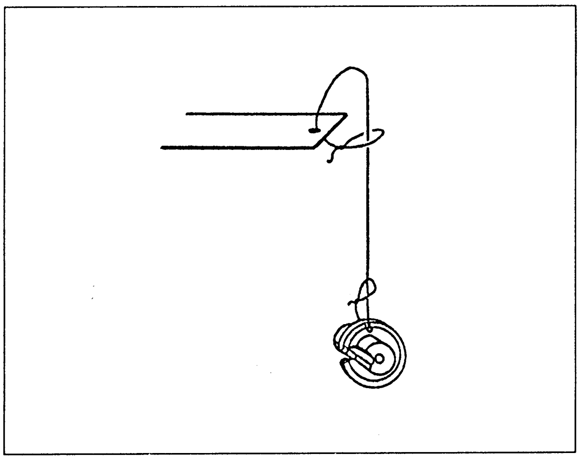


Fig. 3 Attaching a weight to the end of the leaf spring which has a hole in it

Performing the experiment:

Experiment 1: deflection *s* as a function of force *F*

5. Measure the leaf spring's deflection *s* (▶ fig. 1) every time you add a weight, where n (the number of weights) = 1, 2, 3, 4.

Enter your measurements ▶ Table

Table 1 (examples of measurements)

l = 10 cm		
n	$\frac{F}{N}$	$\frac{s}{cm}$
0 1 2 3 4		

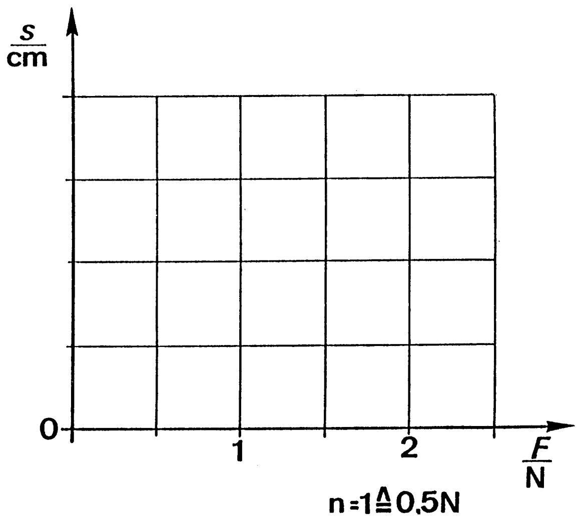
Note:

The values measured for *F* have been rounded up.

Evaluation 1:

6. Draw a graph showing *s* as a function of *F*.

Diagram 1



7. What is the relationship between the deflection *s* and the force *F*?

___

Student's Sheet 4

Experiment 2: deflection *s* where force *F* is constant, but spring length *l* is variable

8. Suspend two weights from the spring.
9. Change the length *l* of the spring according to table 2, measuring the deflection *s* each time. Reset the zero position each time. Why?

Enter the results ▶ Table.

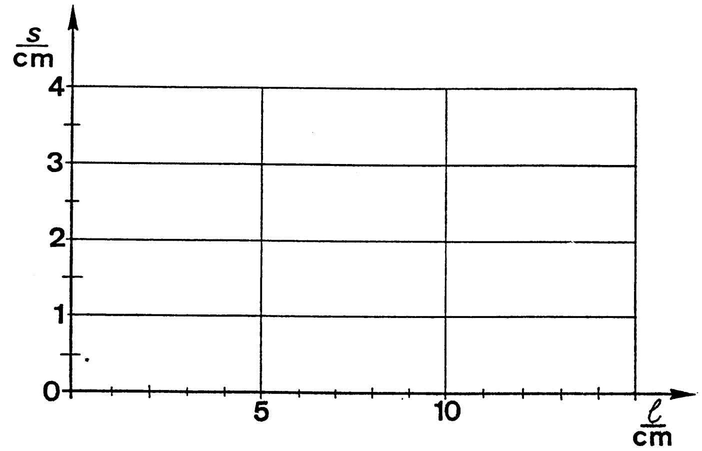
Tabelle 2 (examples of measurements)

n = 2, *F* = 1 N		
$\frac{l}{\text{cm}}$	$\frac{s}{\text{cm}}$	
6		
7		
8		
9		
10		
11		
12		
13		
14		

Evaluation 2:

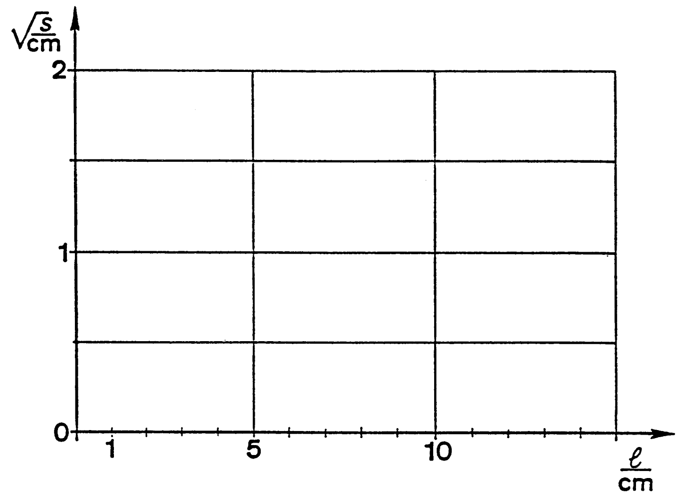
10. Draw a graph showing the deflection *s* as a function of *l*.

Diagram 2



11. Is there a simple relationship between the leaf spring's deflection s and its length l, where the load is constant?

▶ Diagram 3



Student's Sheet 1

Combining forces in the same or opposing directions

Assignment: To find out how forces combine when they are working in the same or opposite directions.

Apparatus:
2 stand bases
1 stand rod, 25 cm
2 stand rods, 50 cm
1 lever
2 sleeve blocks
2 retaining clips
1 set of 6 weights
1 dynamometer, 1.5 N
1 dynamometer, 3 N

Setup:

1. Set up the apparatus as shown in fig. 1.

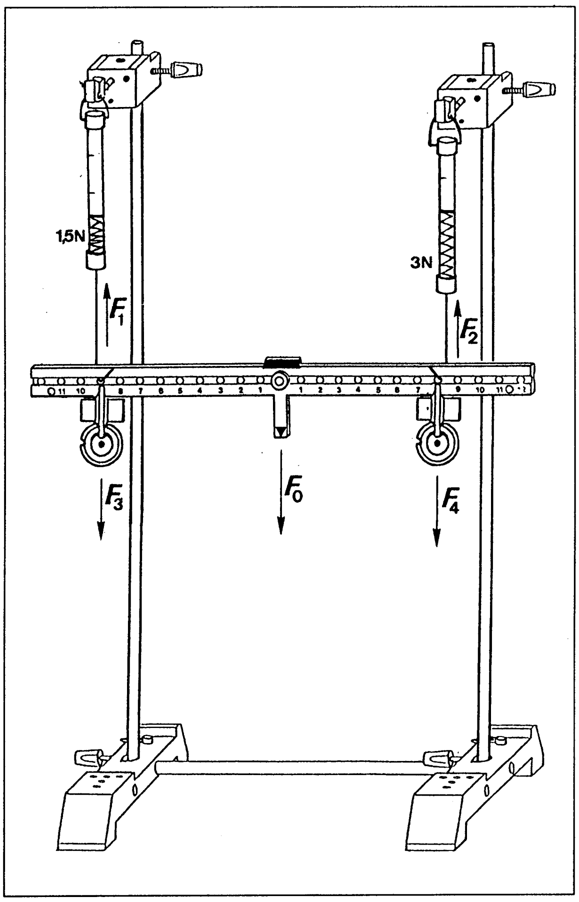


Fig. 1 Experimental setup for investigating the total force resulting from forces working in parallel

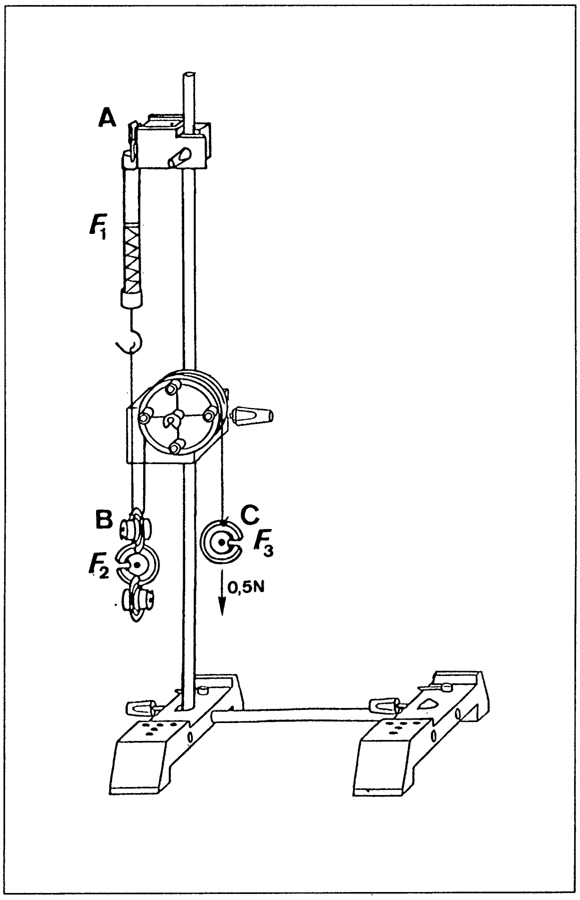


Fig. 2 Experimental setup for combining forces exerted in the same or opposing directions and acting on the same point

Student's Sheet 2

2. Plug the retaining clips into the centre holes of the sleeve blocks.
3. Suspend the dynamometers from the retaining clips.
4. Suspend the lever from the right and left dynamometers, attaching it by the holes labelled 7 in each end.

Performing the experiment:

5. Attach the weights as shown in the table.
6. Enter the values for F_1 and F_2 indicated by the dynamometers ▶ Table.

Table

Position of the weights Number of the hole		$\frac{F_1}{N}$	$\frac{F_2}{N}$
left	right		
7	7		
7	8		
7	4		
10	5		
4	8		
3	10		
2	12		

7. Determine the force due to weight F_0 of the lever.

F_0 =

Evaluation:

8. What forces are acting vertically downwards?

___

___

9. What forces are acting vertically upwards?

___

10. What is the sum total of the forces due to weight?

___

___

11. What is the sum total of the forces indicated by the dynamometers? ▶ Table.

____

12. What can you say about the magnitude of the forces as a whole?

____

____

13. *Exercise 1*

    A lever exerting a force due to weight of 0.4 N is loaded with 5 weights, each weighing 0.5 N. It is suspended from two dynamometers in a horizontal position. One dynamometer is indicating 1.5 N. How great is the force F indicated by the other dynamometer?

____

14. Exercise 2

    a) How great is the force F_2?

____

    b) What does the pulley in the experimental setup do?

____

    c) Which point are three forces acting on?

____

Student's Sheet 1

Combining forces in specified amounts

Assignment: Of three forces which cancel each other out (compensate), you know the magnitude and direction of one and the magnitudes of the other two forces.

Find out the directions in which the forces are acting!

Apparatus:

2 stand bases
1 stand rod, 25 cm
2 stand rods, 50 cm
2 sleeve blocks
1 pulley, 5 cm ⌀
1 pulley, 10 cm ⌀
1 set of 6 weights
1 cord, 75 cm
1 dynamometer, 1.5 N
1 pair of scissors
3 paper clips

Setup:

1. Assemble the stand bases and stand rods as shown ▶ Fig. 1.
2. Screw the sleeve blocks to the top ends of the stand rods and attach one pulley to each.

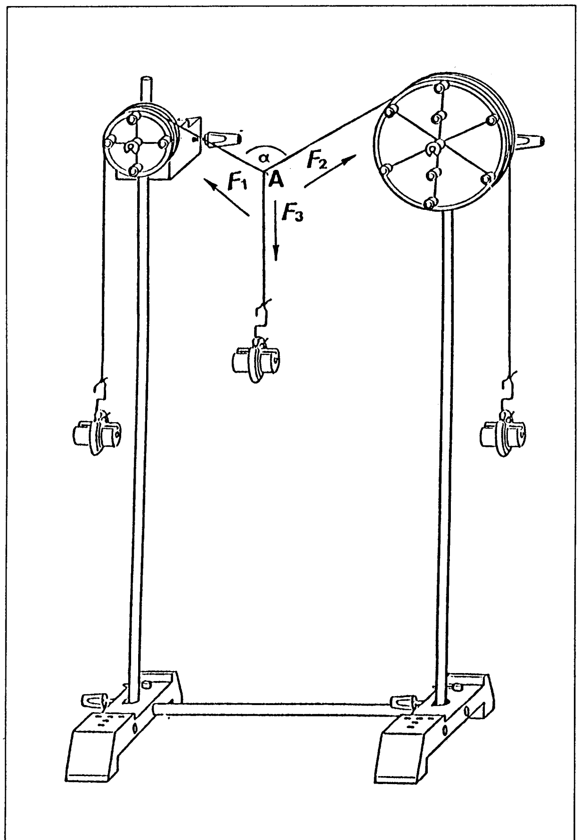


Fig. 1 Experimental setup for investigating three forces of equal magnitude acting on a static point A.

3. Cut a 60 cm length from the cord and tie a loop at each end as shown ▶ Fig. 2.
4. Tie a loop at each end of the remaining length of the cord (15 cm).
5. Thread the short cord onto the longer cord, as shown in fig. 2.
6. Attach a paper clip to each of the remaining loops and hang a weight from each of those paper clips.
7. Thread the cord round the pulleys as shown in fig. 1.

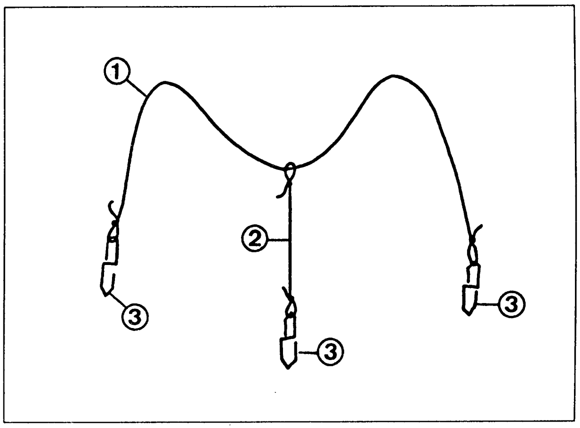


Fig. 2 Supplementary sketch showing how to prepare the cords:
(1) Cord, 60 cm long with loops at both ends
(2) Cord, 15 cm long with loops at both ends
(3) Paper clips or other small wire hooks

Performing the experiment:

Experiment part 1: equal forces acting in different directions

8. Pull on the middle weight and then release it.
   Watch the directions of the cords converging on point A.
   Observation:
   ____

9. Move the sleeve blocks to different heights on the stand rods and fasten them in place.
   What do you observe?
   ____

10. Reduce the distance between the stand bases by ca. 10 cm.
    Move the sleeve blocks around.
    Compare the angles between the different cords.
    Observations:
    ____

Student's Sheet 3

Experiment part 2:
different forces, different directions

11. Attach 2 weights each to the cords on the left and right, and 3 weights to the one in the middle ▶ Fig. 3.

Repeat the working steps described in part 1 of the experiment.

Leave the apparatus in place for the time being.

What do you observe?

____

____

____

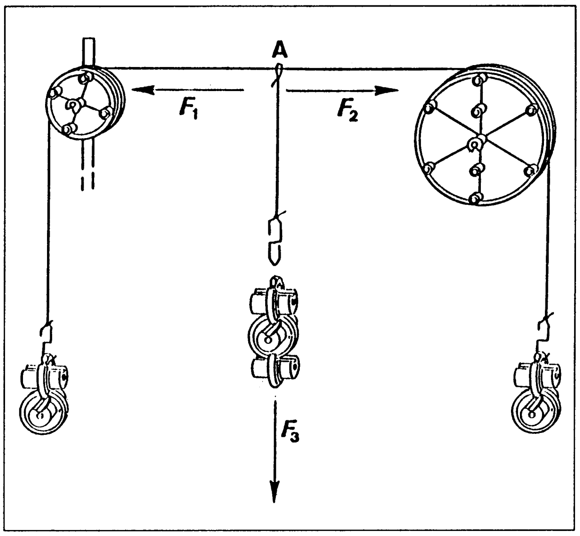


Fig. 3 Experimental setup for investigating different forces acting on a static point A.

Evaluation:

Experiment part 1

12. In fig. 3, the force due to weight F_3 = 0.5 N is shown as an arrow (vector) 5 cm long.

F_3 acts on point A. Forces F_1 and F_2 also act on point A.

Now add F_1 and F_2 to the drawing in fig. 4, in the form of vectors (arrows).

a) What angles do the directions of the vectors originating at point A form with one another?

Give reasons!

____

____

____

b) What is the magnitude of the forces acting on point A in each case?

____

____

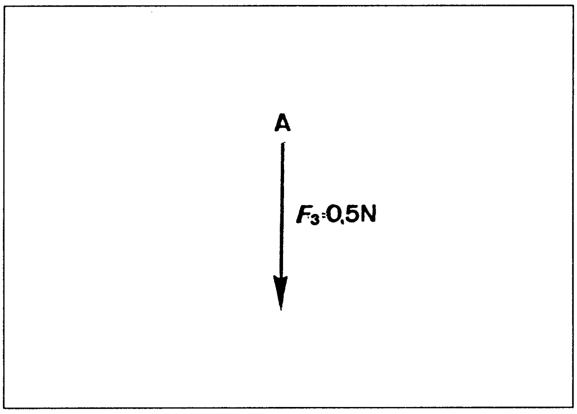


Fig. 4 Sketch illustrating step 12.

Fig. 4.1 Solution to step 12

Student's Sheet 4

13. You add vectors together by – figuratively speaking – joining the arrows together. The sum is a single long arrow which leads from the beginning of the first arrow to the tip of the last arrow.

    Drawing exercise:

    Draw vectors $F_1 + F_2 + F_3$

14. What is the sum of the forces $F = F_1 + F_2 + F_3$?

    ____

15. What is the sum of the forces $F_1 + F_2$?

    $F_1 + F_2 = -F_3$

    Show it in terms of vectors! ▶ Fig. 4.3

    Experiment part 2

16. Add together the force vectors F_1, F_2 and F_3 from the experimental setup described in step 11.

    Compare the angle between F_1 and F_2 in the diagram with the angle in the experimental setup.

    ____

    ____

    Assignments:

17. At point A on a taut line, a force F_1 of 1 N is pulling to the left and a force F_2 of 1 N is pulling to the right.

    What force F_3, working at right angles to the line, is required in order to form an angle of $\alpha = 90°$ at point A?

    a) Draw a vector diagram. Determine the magnitude of force F_3 from the diagram.

    ____

    b) Calculate F_3.

    ____

    ____

    ____

Fig. 4.2 Vector addition for step 13.

Fig. 4.3 Vector addition for step 15.

Fig. 4.4 Vector addition for step 16.

c) Check the result by experiment.

Note:

re. step 15:

You can illustrate a force of F_3 in the experimental setup shown in fig. 1 by pulling the dynamometer upwards with a force of 0.5 N acting on point A.

Fig. 4.5 Vector addition for step 17.

Student's Sheet 1

Breaking a force down into force components

Assignment: To break down a force into two forces acting in specified directions and measure them.

Apparatus:
2 stand bases
1 stand rod, 25 cm
2 stand rods, 50 cm
2 sleeve blocks
2 retaining clips
1 set of 6 weights (2 are required)
1 dynamometer, 1.5 N
1 dynamometer, 3 N
1 cord, 30 cm
1 paper clip (wire)
1 sheet of paper, DIN A4
1 pair of scissors

Setup:

1. Look at fig. 1.
2. Trace the template overleaf onto your piece of paper **(1)** ▶ Fig. 2.
3. Set up the apparatus as shown in fig. 1.
4. Suspend the 1.5 N dynamometer ▶ **(5)** from the lower weight.

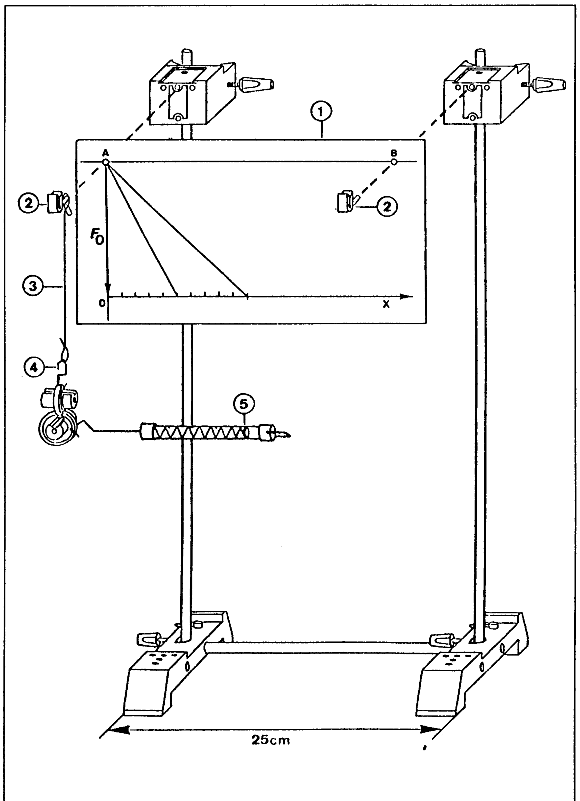
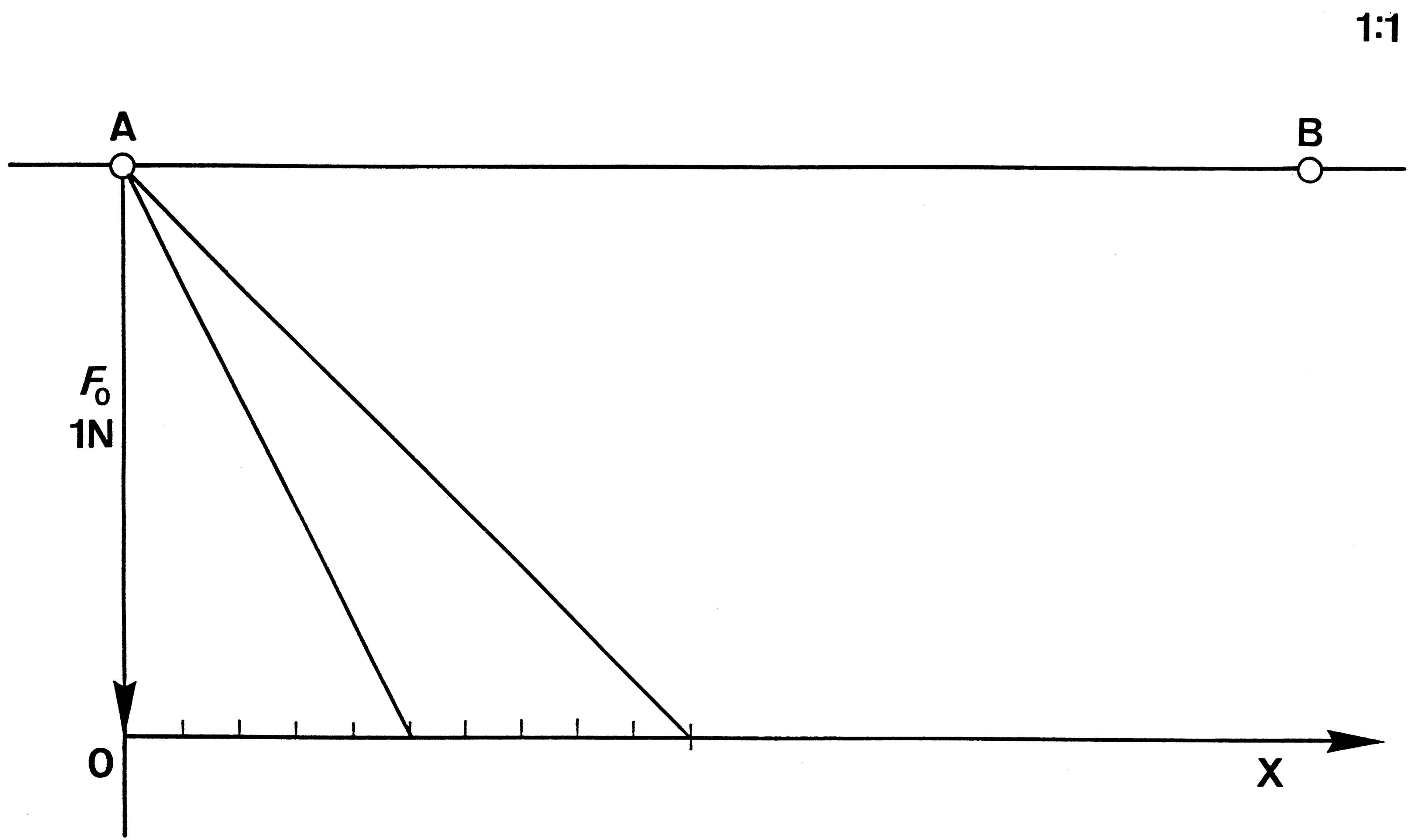


Fig. 1 Exploded diagram of the experimental setup for breaking down a force into its force components
(1) Sheet of paper based on template ▶ fig. 2
(2) Retaining clips
(3) Cord, 30 cm long, with loops at both ends
(4) Paper clip fashioned to act as a hook



Template for copying. Scale 1:1. Make holes at positions A and B. Attach to your experimental apparatus ▶ fig. 1

Performing the experiment:

Experiment part 1:
determining the horizontal force *F*(x) required to deflect a pendulum

Note: F(x) is pronounced "F of x".

5. Hold the dynamometer horizontally and move the pendulum to the right until the cord has moved 10 cm along the *x*-axis.
6. Take a reading for force *F(x)* on the dynamometer where *x* = 10 cm.
   Enter the reading ▶ Table.
7. Do the same thing for the other values of *x* in table *F(x)*, entering your measurements each time.

Experiment part 2
determining the tension force $\overline{F}$ *(x)* of the pendulum's cord

Note: $\overline{F}$ (*x*) is pronounced "*F* diagonal of *x*".

8. Insert the 1.5 N dynamometer between the cord and weights, as shown in fig. 3.
9. Incline the pendulum so that it coincides with the value markings along the *x*-axis, as you did before. Use the 3 N dynamometer for this purpose ▶ Fig. 3.
   Note down the tension force $\overline{F}$ (*x*) acting in the direction of the cord and indicated by the 0.5 N dynamometer for each value of *x* ▶ Table.

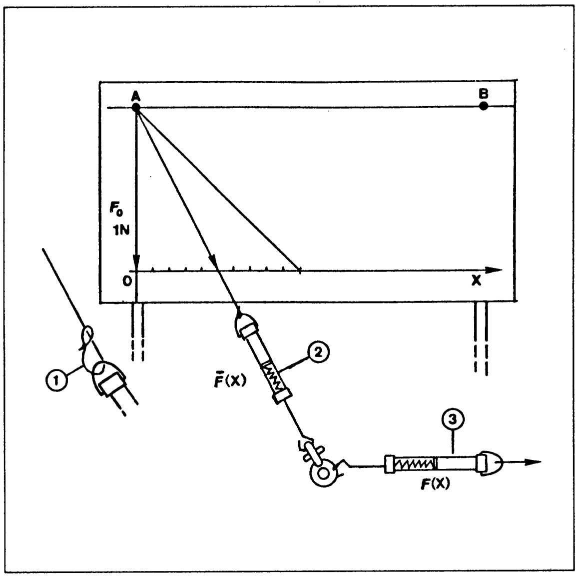


Fig. 3 Experimental setup according to fig. 1, for measuring the force of $\overline{F}$(*x*) in the direction of the cord.
(1) Supplementary diagram showing how to attach the second dynamometer **(2)**
(2) 1.5 N dynamometer
(3) 3 N dynamometer

Evaluation:

10. What is the relationship between the horizontal deflection *x* and the force *F(x)* acting horizontally?

Table

x / cm	*F(x)* / N	$\overline{F}(x)$ / N
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

11. What is tension force $\overline{F}(x)$ if no horizontal deflection force is being exerted?

12. Forces are directed quantities. They can be represented by arrows (vectors).
The direction of the arrow indicates the direction in which the force is acting.
The length of the arrow defines the magnitude of the force.
You must specify the scale used.
What was the length used to represent F_0 = 1 N in the illustration in fig. 2?

13. If you mark off forces along the x-axis (fig. 2), what force is needed for a deflection of x = 10 cm?

14. How can you read the tension force $\overline{F}(x)$ directly from the diagram?

15. What is the relationship between F_0, $F(x)$ and $\overline{F}(x)$?

String pendulum

Assignment: To determine the factors on which the period of oscillation *T* of a string pendulum depends.

Apparatus:
2 stand bases
1 stand rod, 25 cm
1 stand rod, 50 cm
1 sleeve block
1 retaining clip
1 set of 6 weights (3 required)
1 cord, ca. 130 cm
1 tape measure
1 stopwatch
1 universal marker pen
1 paper strip (self-adhesive, ca. 20 cm long)

Setup:

1. Set up the stand bases and stand rods as shown in fig. 1
2. Fasten the sleeve block to the upper end of the stand rod.
3. Plug the retaining clip **(1)** into one of the top holes in the sleeve block.
4. Tie the cord to a weight and thread it through the retaining clip **(1)**. Regulate the length of the resulting pendulum so that the weight is only about 2 mm away from the surface of the workbench.
5. Attach the cord to a screw **(2)**: wind it five times round the screw!

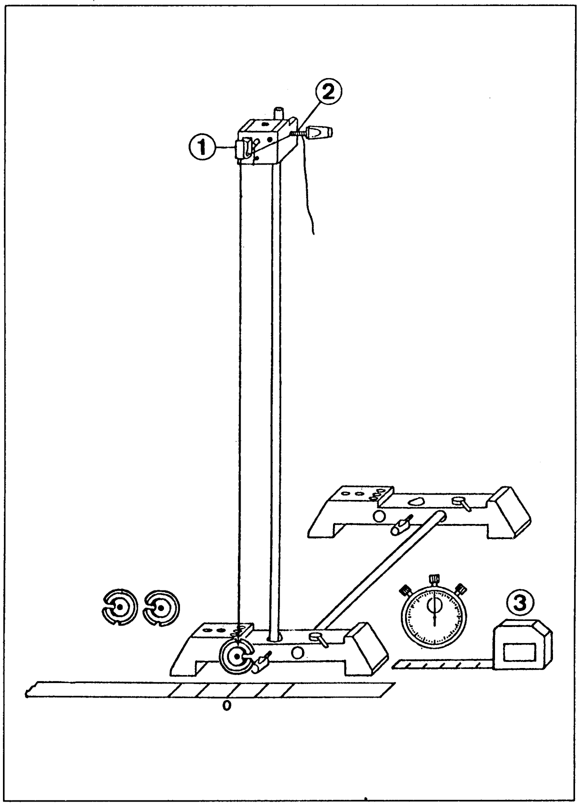


Abb. 1 Experimental setup: string pendulum
(1) Retaining clip
(2) Screw in sleeve block
Wind the end of the pendulum string round the screw (ca. 5 x)

Performing the experiment:

Experiment part 2: period of oscillation as a function of amplitude

6. Fix the paper strip to the surface of the bench directly under the pendulum. Mark the zero reference point and make further marks at intervals of 3 cm, 6 cm and 9 cm.
7. Measure the length of the pendulum *l*.
   The pendulum's length *l* is the distance between the point A from which the cord is suspended and the centre of mass M (centre of gravity) of the pendulum's bob (weight) ▶ Fig. 2.
   Enter the value for *l* in Table 1.
8. Move the string pendulum 3 cm to one side and allow it to swing freely.
   Use the stopwatch to measure the time 10 *T* taken by the pendulum to perform 10 oscillations.
   Enter your measurements ▶ Table 1.
9. Measure the equivalent values where the amplitude s_0 = 6 cm and 9 cm.
   Enter the results ▶ Table 1.

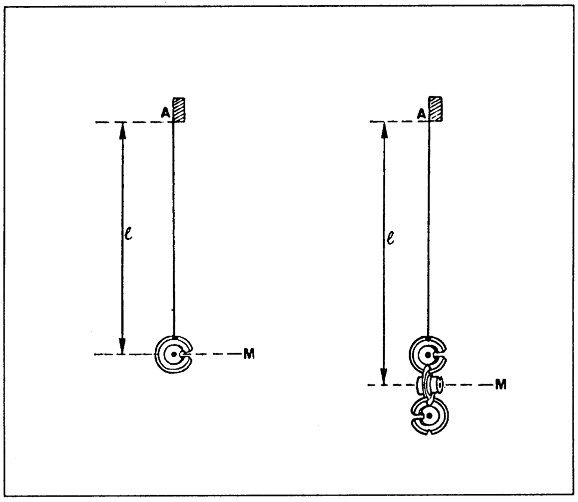


Fig. 2 Measuring the length of the pendulum *l*
A = point of suspension, M = centre of inertia (centre of gravity)

Table 1

	Length of pendulum: *l* =		
Amplitude	3	6	9
Time taken for 10 oscillations $\frac{10\,T}{s}$			
Period of oscillation $\frac{T}{s}$			

Experiment part 2: period of oscillation *T* as a function of the pendulum's mass *m*

10. Attach 3 weights to the pendulum to act as its mass (*m* = 150 g).
11. Choose a pendulum length *l* = 45 cm, as shown in fig. 2 on the right.
12. Push the pendulum sideways (by applying pressure to the middle weight) until it is swinging to a distance of 2 cm on either side of the zero position.
13. Measure the time 10 *T* taken to complete 10 oscillations. Enter the results ▶ Table 2.
14. Remove two weights.
15. Measure out a new length *l* = 45 cm, as shown in fig. 2 on the left.
16. Allow the pendulum to swing freely and measure the time 10 *T* taken to complete 10 oscillations. Enter your measurements ▶ Table 2.

Table 2

	Length of pendulum l =	
No. of weights n	3	1
Mass of pendulum $\frac{m}{g}$	150	50
Time taken for 10 oscillations $\frac{10\,T}{s}$		
Period of oscillation $\frac{T}{s}$		

Experiment part 3: period of oscillation T as a function of pendulum length l

17. Use one weight as the pendulum's bob.
18. Set a pendulum length of l = 10 cm ▶ Fig. 2, left
19. Move the pendulum 1 cm to one side and allow it to swing freely. Measure the time 10 T taken to complete 10 oscillations.

    Enter your measurements ▶ Table 3.
20. Perform the experiment with the other pendulum lengths l specified in Table 3.

    Tips:

    It is a good idea to measure out the required cord lengths beforehand and then mark them on the cord using the universal marker.

    For longer pendulum lengths (l > 45 cm), move the stand forward until the stand base is standing flush with the edge of the workbench.

    Measure 10 T for each different length.

    Enter values for 10 T and T ▶ Table 3.
21. Display the period of oscillation T as a function of pendulum length l, in the form of a graph

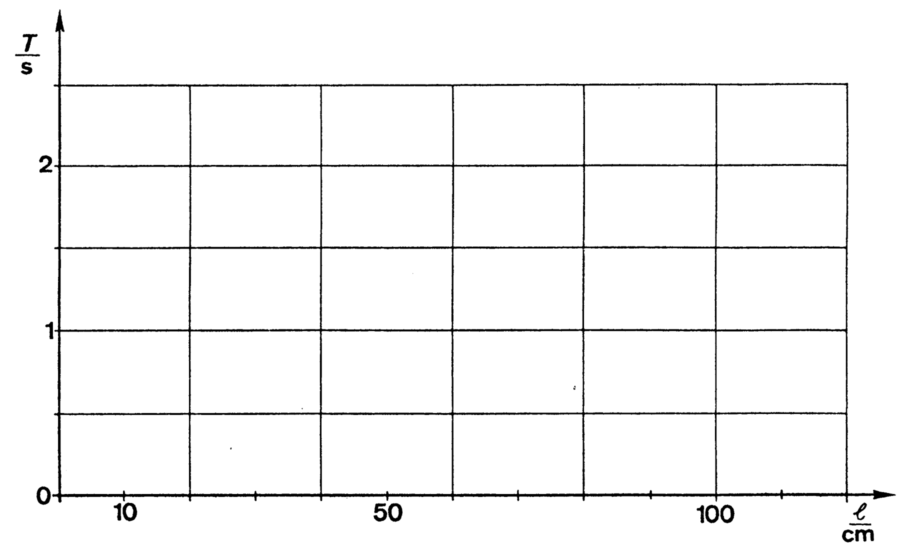


Fig. 3 Period of oscillation T of a string pendulum as a function of pendulum length l

Student's Sheet 4

Table 3

Length of pendulum $\frac{l}{\text{m}}$	Time $\frac{10\,T}{\text{s}}$	Period of oscillation $\frac{T}{\text{s}}$
10		
20		
30		
40		
60		
80		
100		
120		

Evaluation:

22. What is the effect of amplitude on period of oscillation *T*?

___

23. How does the mass of the pendulum *m* affect the period of oscillation *T*?

___

24. How does the string pendulum's period of oscillation *T* depend on the length of the pendulum *l* ?

___

___

25. With the help of the diagram, find out how to double the period of oscillation by changing the length of the pendulum. By how many times do you need to increase the length of the pendulum?

___

Bar pendulum

Assignment: To find out where the bar pendulum's axis of rotation (fulcrum) should be located so that the period of oscillation is as small as possible.

Apparatus:
2 stand bases
2 stand rods, 50 cm
1 sleeve block
1 knockout spindle, 5.5 cm
1 lever
1 stopwatch

Setup:

1. Assemble the items of apparatus as shown in fig. 1.
2. Insert the spindle **(1)** into a hole in the sleeve block.
3. Slide the balancing rider **(2)** to the centre of the lever.
4. Here we are using the lever as a "bar pendulum". The holes which we are going to use as the axes of oscillation are numbered.
5. What is the number n of the hole matching the of the "bar pendulum"'s axis of rotation, as shown in fig. 1?

____

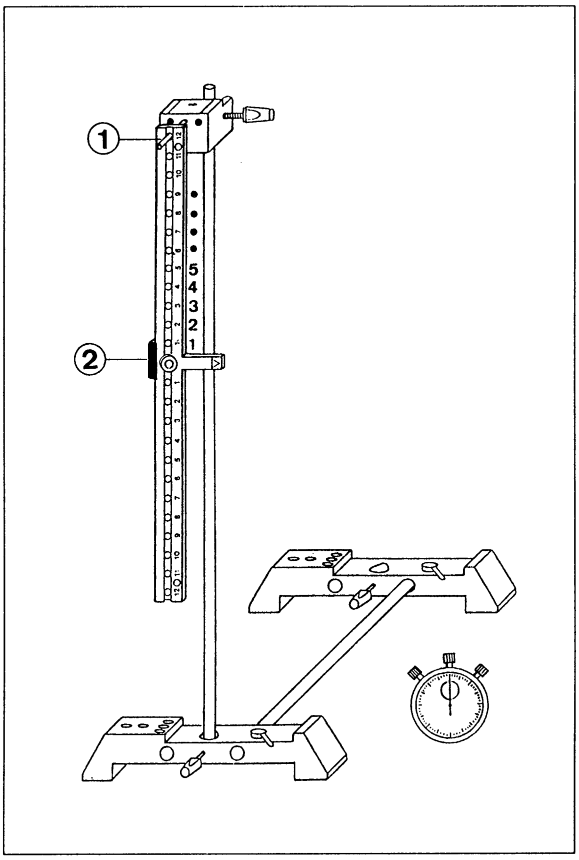


Fig. 1 Experimental setup: bar pendulum
(1) Knockout spindle
(2) Tare rider

Performing the experiment:

6. Swing the bar pendulum.

   The period of oscillation *T* refers to the time required by the pendulum to swing through the same position (e.g. the zero point) in the same direction.

7. Move the pendulum through a full oscillation by hand.

8. Use the stopwatch to measure the time taken to complete 10 oscillations.
   Enter a value for the time taken for one oscillation, the period of oscillation *T*.

   ▶ Table.

9. Determine the period of oscillation *T* for all the other positions in the same way.

   Enter your readings ▶ Table.

n	$\frac{T}{s}$
12	
11	
10	
9	
8	
7	
6	
5	
4	
3	
2	
1	

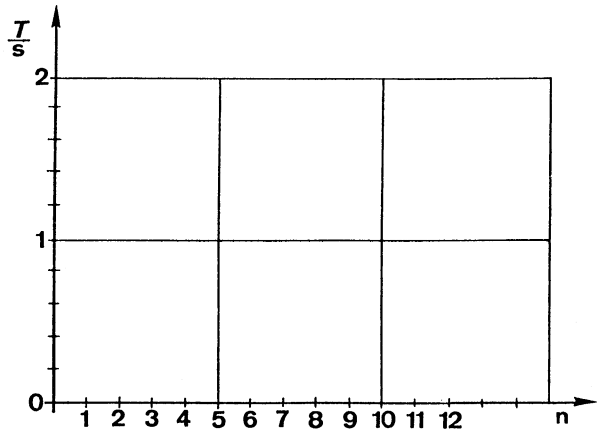
Note:
Where n = 2 and n = 1, calculate the period of oscillation *T* as the mean value of 5 oscillations.
(Double the measured value and divide by 10).

Student's Sheet 3

Evaluation:

10. Draw a graph showing *T* as a function of n.

Diagram



11. Which hole n causes the pendulum's period of oscillation to be greatest?

____

12. Which hole n causes the pendulum's period of oscillation to be smallest?

____

13. Can the spindle be inserted into a hole in such a way that the pendulum acts as the seconds hand of a clock?

____

____

Spring pendulum

Assignment: To find out what factors determine the period of oscillation T of a spring pendulum.

Apparatus:
2 stand bases
1 stand rod, 25 cm
1 stand rod, 50 cm
1 sleeve block
1 retaining clip
1 helical spring, 1.5 cm ⌀
1 helical spring, 2 cm ⌀
1 set of 6 weights
1 pointer
1 stopwatch

Setup:

1. Slide two pointers onto the 50 cm stand rod.
2. Assemble the stand bases, stand rods and sleeve block as shown in fig. 1.

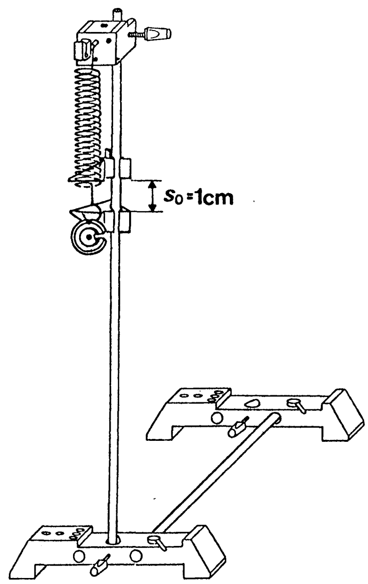


Fig. 1 Experimental setup, spring pendulum

Student's Sheet 2

3. Attach the helical spring **(1)** (▶ fig. 2) to the sleeve block using the retaining clips.
4. Set the top pointer so that it points to the bottom end of the helical spring but does not prevent the latter from swinging.
5. Move the lower pointer so that it is 1 cm below the top pointer.

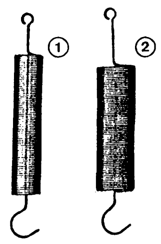


Fig. 2 **(1)** helical spring, 1.5 cm ⌀
(2) helical spring, 2 cm ⌀

Performing the experiment:

Experiment part 1: period of oscillation *T* as a function of amplitude

6. Move the weight to one side until it is next to the pointer.
Release.
7. Measure the time taken to complete 10 oscillations (10 *T*).
Enter your measurements ▶ Table 1.
8. Move the bottom pointer until it is 2 cm from the top one.
Once again, measure the time taken to complete 10 oscillations (10 *T*).
Enter your measurements ▶ Table 1.

Experiment part 2: period of oscillation *T* as a function of the pendulum's mass *m*.

9. Add 1 to 6 weights (of 50 g each) to the pendulum one after the other, measuring the period of oscillation *T* each time.
Deflection: 1 cm
Enter your findings ▶ Table 2.

Experiment part 3: period of oscillation *T* as a function of the spring's hardness

10. A spring is described as hard if considerable force is needed to change its length.
Otherwise it is described as "soft".
Which of the two helical springs is harder, **(1)** or **(2)**? ▶ Fig. 2

____

11. Enter "hard" and "soft" respectively next to **(1)** and **(2)** in Table 3.
12. Compare the periods of oscillation of the two helical springs under an equal load (*m* = 100 g). Enter your findings ▶ Table 3.

Student's Sheet 3

Observations and measurements:

Table 1 for experiment part 1

Deflection s_0	1 cm	2 cm
Time taken for 10 oscillations 10 *T*		
Period of oscillation *T*		

Table 2 for experiment part 2

Mass of pendulum *m*	50 g	100 g	150 g	200 g	250 g	300 g
Time taken for 10 oscillations 10 *T*						
Period of oscillation *T*						

Table 3 for experiment part 3

Helical spring	**(1)**	**(2)**
Time taken for 10 oscillations 10 *T*		
Period of oscillation *T*		

Evaluation:

13. Work out the period of oscillation *T* and enter the values ▶ last line of the tables.
14. How does a spring pendulum's period of oscillation *T* depend on the amplitude?

____

15. Can you double a pendulum's period of oscillation *T* by changing the pendulum's mass *m*?

____

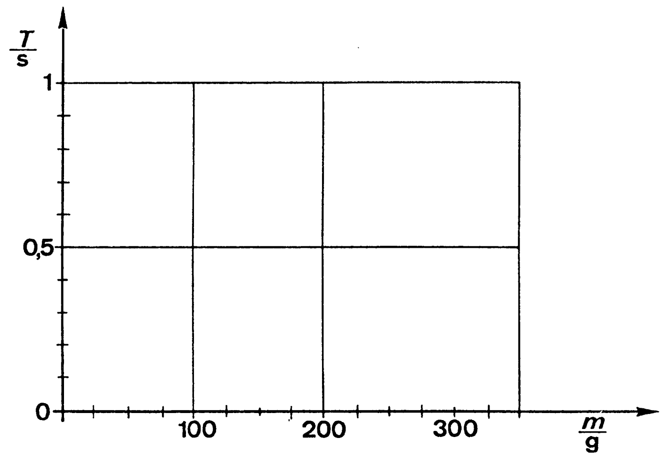
Give an example!

____

____

Student's Sheet 4

16. Draw a graph showing the period of oscillation T as a function of the pendulum's mass m.
Diagram



17. What effect does a helical spring's hardness have on the spring pendulum's period of oscillation T?

Hints:

Theory provides the following equation for the spring pendulum's period of oscillation T:

$$T = 2\,\pi \cdot \sqrt{\frac{m}{D}}$$

D = spring constant ▶ Experiment 5.

Strictly speaking, the suspended mass of the helical spring itself should also be included as part of the pendulum's mass. You can include it at a ratio of about $\frac{1}{3}$ ein.

You will find more on this topic ▶ STM Vibration and oscillation, Experiment 1.3.

Student's Sheet 1

Leaf spring oscillations

Assignment: To calculate a leaf spring's frequency f as a function of its length l.

Apparatus:
2 stand bases
1 stand rod, 25 cm
1 universal socket
1 metal plate
1 leaf spring
1 stopwatch

Setup:

1. Assemble the items of apparatus as shown in fig. 1.
2. Position the leaf spring so that l = 40 cm.

   In doing so, fit the metal plate **(1)** in such a way that it fits flush with the universal socket's front edge.

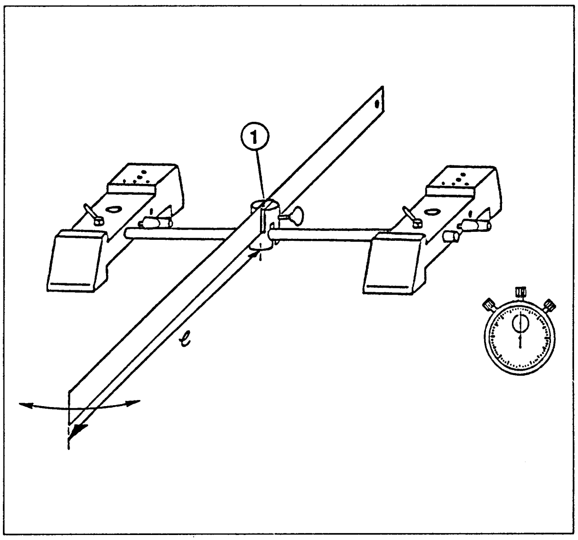


Fig. 1 Experimental setup for determining the frequency f of a vibrating leaf spring as a function of its length.

Performing the experiment:

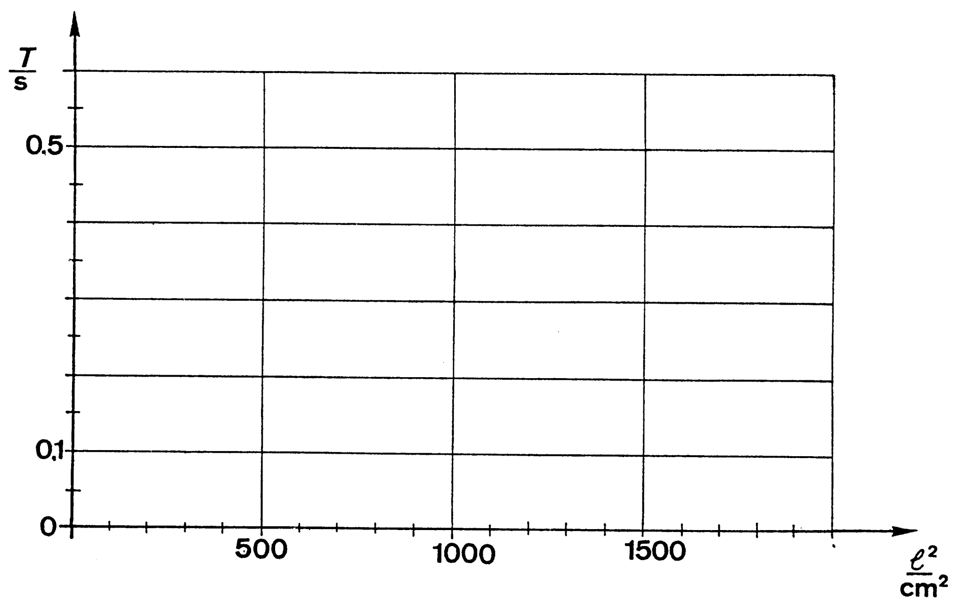
3. Make the leaf spring vibrate.
   Use the stopwatch to measure the period of oscillation T (as the mean value calculated from 10 oscillations), and note down your measurements ▶ Table.
4. Repeat the above measurement where l = 39 cm, 38 cm, 37 cm, ... 30 cm (a total of 11 times).
   Enter T ▶ Table.

Evaluation:

5. The theory of leaf spring behaviour states that there is a simple relationship between l^2 and T.
   You should confirm that this is so.
   To do so, work out l^2 for each measurement and enter it in the table. ▶ Table.

$\frac{l}{\text{cm}}$	$\frac{T}{\text{s}}$	$\frac{l^2}{\text{cm}^2}$
40	0.51	
38	0.46	
36	0.41	
34	0.36	
32	0.33	
30	0.28	

6. Draw a graph showing T as a function of l^2.



What do you observe?

____

7. If you make l much shorter than we did in this experiment, it is no longer possible to measure the spring's period of oscillation T using a stopwatch.

   However, you can use this diagram to work out short periods of oscillation, if you know the length l of the spring in each case.

   Exercise:

   What is the spring's period of oscillation T, where l = 20 cm?

   ____

   ____

8. What can you observe in the case of vibrating springs where the length l is very short?

   ____

   ____

9. *Additional exercise:*

   The physical variable "number of oscillations per second" is described as frequency f.
   The unit of measurement is 1 Hz (1 Hertz).

   What is the relationship between the period of oscillation T and the frequency f?

   ____

   Calculation of the frequency where l = 20 cm. ▶ 7.

   ____

   ____

Two-sided lever

Assignment: To restore the equilibrium of a two-sided lever.

Apparatus:

1 lever with pointer
1 knockout spindle
1 set of 6 weights
1 dynamometer, 1.5 N
1 dynamometer, 3 N
2 stand bases
1 stand rod, 25 cm
1 stand rod, 50 cm
2 sleeve blocks
2 retaining clips
1 double scale

Student's Sheet 2

Setup:

1. Set up the apparatus as shown in fig. 1. Fasten two sleeve blocks to the vertical stand rod.

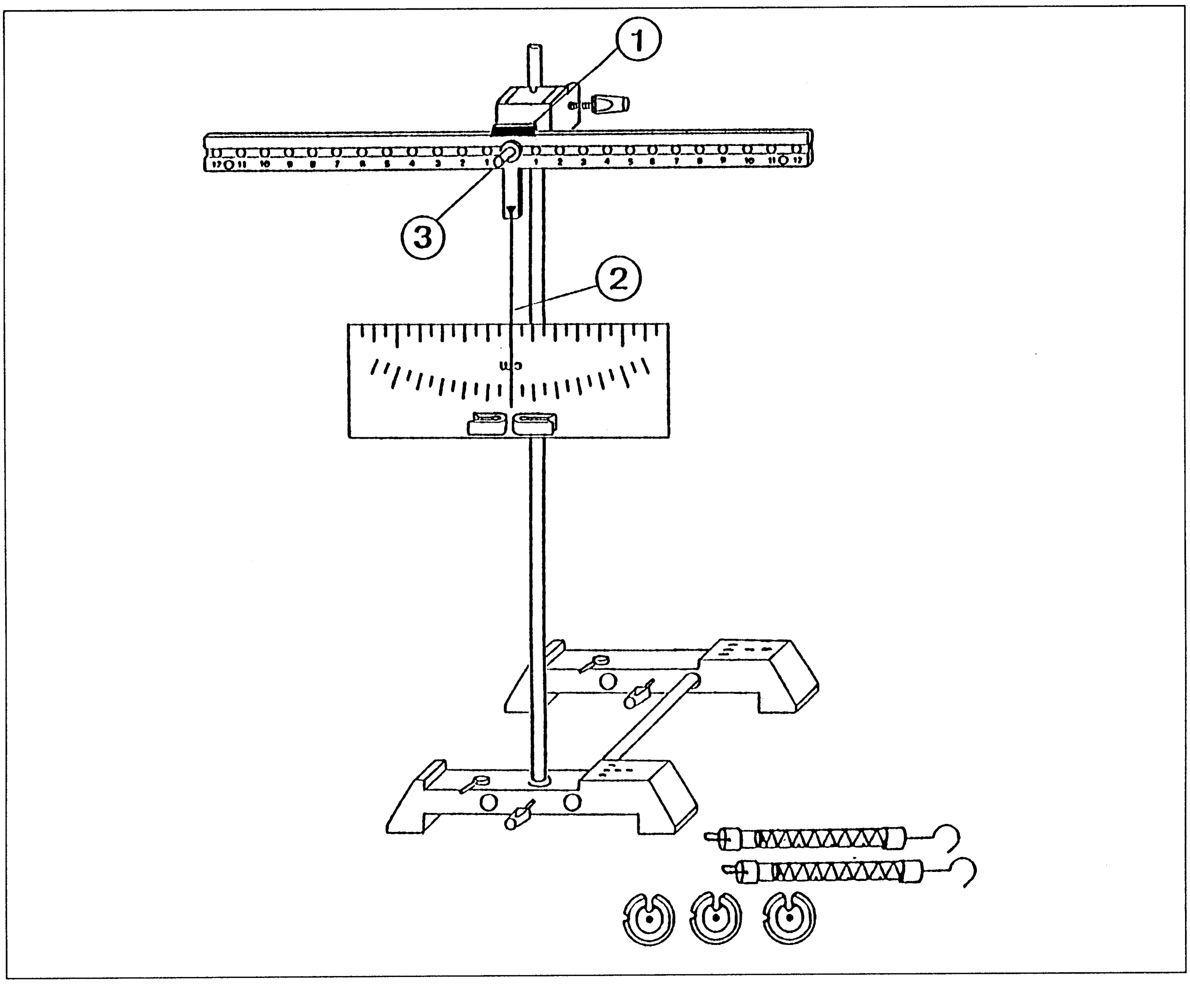


Fig. 1 Setup for experiments using two-sided levers
(1) Balancing rider **(2)** Pointer **(3)** Spindle

2. Plug the spindle into the centre hole of the top sleeve block.
3. Fit the lever to the spindle at its centre of oscillation.
4. Slide the balancing rider **(1)** along the lever until the pointer **(2)** is pointing vertically downwards (zero position).
5. Attach the scale to the lower of the two sleeve blocks using two retaining clips. ▶ Fig. 2.

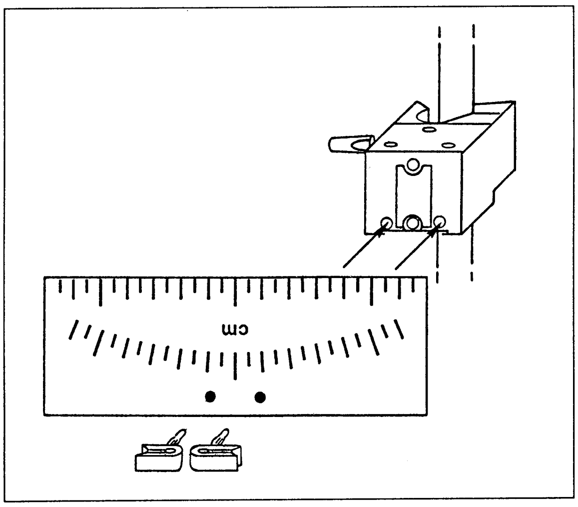


Fig. 2 Attaching the scale to the sleeve block using two retaining clips

Student's Sheet 3

Performing the experiment:

Experiment part 1:

▶ Fig. 3

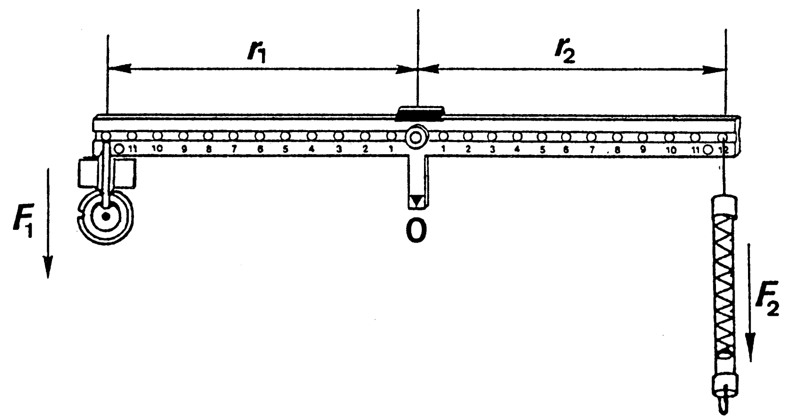


Fig. 3 Two-ended lever
F_1 : load r_1 : work arm
F_2 : force r_2 : power arm

6. Suspend two weights F_1 = 1.0 N from the left arm of the lever (load arm) at position 12 (r_1 = 18 cm).
7. Hook the 1.5 N dynamometer to the right arm of the lever (power arm) at position 12 (r_2 = 18 cm).
8. Pull the dynamometer downwards until the pointer is once again indicating "zero".
9. Read off the force required from the dynamometer and enter the value ▶ Table 1.
   In table 1, the values which remain constant through all parts of the experiment are underlined.
10. Move the load F_1 to position 6 (r_1 = 9 cm) and then 3 (r_1 = 4.5 cm), and measure the force F_2 required to return the pointer to zero in each case.

Experiment part 2:

11. Attach 1 (0.5 N), 2 (1.0 N) and then 3 (1.5 N) weights one after the other to position 12 on the lever, measuring the force F_2 every time you add a weight.

Experiment part 3:

12. Attach two weights F_1 = 1.0 N to position 6 (r_1 = 9 cm) and measure the force F_2 at positions 12 (r_2 = 18 cm), 6 (r_2 = 9 cm) and 3 (r_2 = 4.5 cm).

    Tips:

    While you are hanging the weights and dynamometer, hold the lever firmly at its fulcrum so that it does not fall sideways.

    The distance between the individual holes is 1.5 cm. Thus position 12 is 18 cm away from the axis of rotation.

    Always hold the dynamometer so that it is absolutely perpendicular.

Observations and measurements:

Table 1

Variable	Unit	Experiment part 1			Experiment part 2			Experiment part 3		
No. of weights	–	2	2	2	1	2	3	2	2	2
Load F_1	N	1.0	1.0	1.0	0.5	1.0	1.5	1.0	1.0	1.0
Work arm r_1	cm	18	9	4.5	18	18	18	9	9	9
Power arm r_2	cm	18	18	18	18	18	18	18	9	4,5
Force F_2	N									
$F_1 \cdot r_1$	N · cm									
$F_2 \cdot r_2$	N · cm									

Evaluation:

13. Complete Table 2:

Table 2

Load	constant	greater	constant
Work arm	smaller	constant	constant
Power arm	constant	constant	smaller
Force			

14. Complete the last two lines in table 1.
What conditions must be satisfied if the lever is to remain in equilibrium?

____

____

Two-sided lever with several forces acting upon it

Assignment:

- To load one side of a lever with weights at various points.
- To a) calculate
  b) determine empirically
  the force at a given point on the opposite side of the lever.

Apparatus

1 lever with pointer
1 knockout spindle
1 set of 6 weights
1 dynamometer, 1.5 N
1 dyanmometer, 3 N
2 stand bases
1 stand rod, 25 cm
1 stand rod, 50 cm
2 sleeve blocks
2 retaining clips
1 double scale

Setup:

1. Assemble the apparatus as shown in fig. 1.
   Fasten two sleeve blocks to the vertical stand rod.

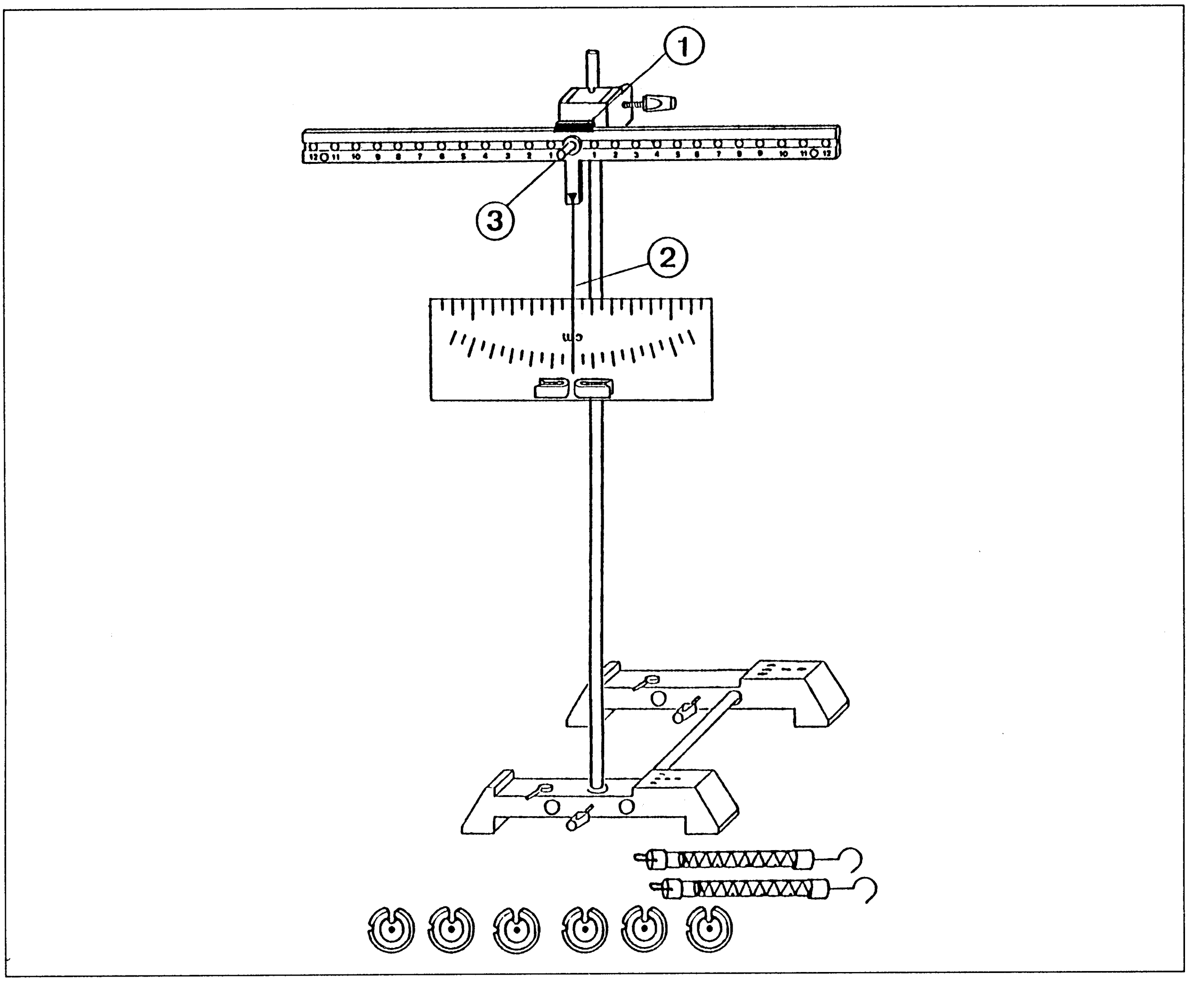


Fig. 1 Setup for experiments using two-sided levers
(1) Balancing rider **(2)** Pointer **(3)** Spindle

2. Plug the spindle into the centre hole of the top sleeve block.
3. Fit the lever to the spindle at its centre of oscillation.
4. Slide the balancing rider **(1)** along the lever until the pointer **(2)** is pointing vertically downwards (zero position).

   Attach the scale to the lower of the two sleeve blocks using two retaining clips. ▶ Fig. 2.

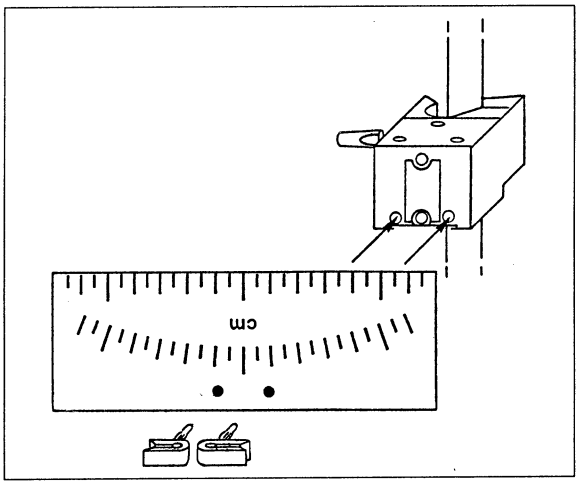


Fig. 2 Attaching the scale to the sleeve block using two retaining clips

Student's Sheet 3

Performing the experiment:

5. Calculate the force needed to maintain equilibrium under the loads specified in the table.
   Enter the results ▶ Table.
   Markings ▶ Fig. 2

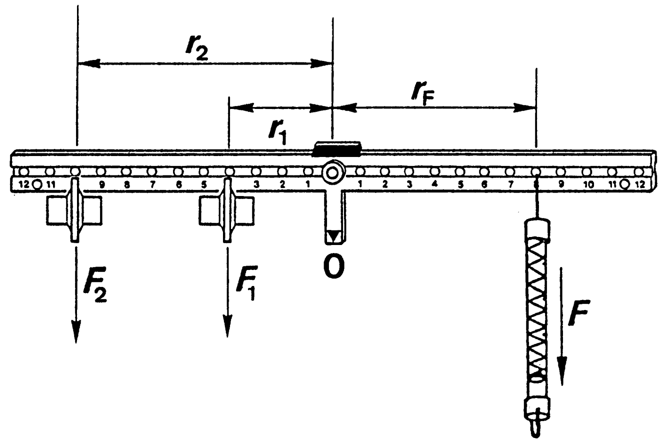


Fig. 3 Two-sided lever
F : force; F_1, F_2 : loads

6. Check your calculations by experimentation. Enter the results ▶ Table.

   Caution!

   Hold the lever steady while you are removing or replacing weights.

7. How much force (rounded to the nearest decimal point) is exerted by one metal weight?

___

Table

Load F_1		0.5 N	1.0 N	1.0 N	1.0 N
Load F_2		0.5 N	0.5 N	0.5 N	0.5 N
Load F_3		—	—	1.0 N	1.5 N
Work arm r_1		6.0 cm	7.5 cm	4.5 cm	4.5 cm
Work arm r_2		15.0 cm	18.0 cm	12.0 cm	9.0 cm
Work arm r_3		—	—	18.0 cm	15.0 cm
Power arm r		12.0 cm	15.0 cm	12.0 cm	18.0 cm
Force F	calculated				
	measured				

Student's Sheet 4

Evaluation:

8. What is the lever principle when several weights are involved?

____

Pair of scales

Assignment: To determine masses using a pair of scales and a set of weights.

Apparatus

1 lever with pointer
1 knockout spindle
2 balance pans with stirrups
1 set of 6 weights
1 double scale
2 retaining clips
2 stand bases
1 stand rod, 25 cm
1 stand rod, 50 cm
2 sleeve blocks
miscellaneous items from the sets of apparatus

Student's Sheet 2

Setup:

1. Assemble the stand bases and stand rods as shown in fig. 1.

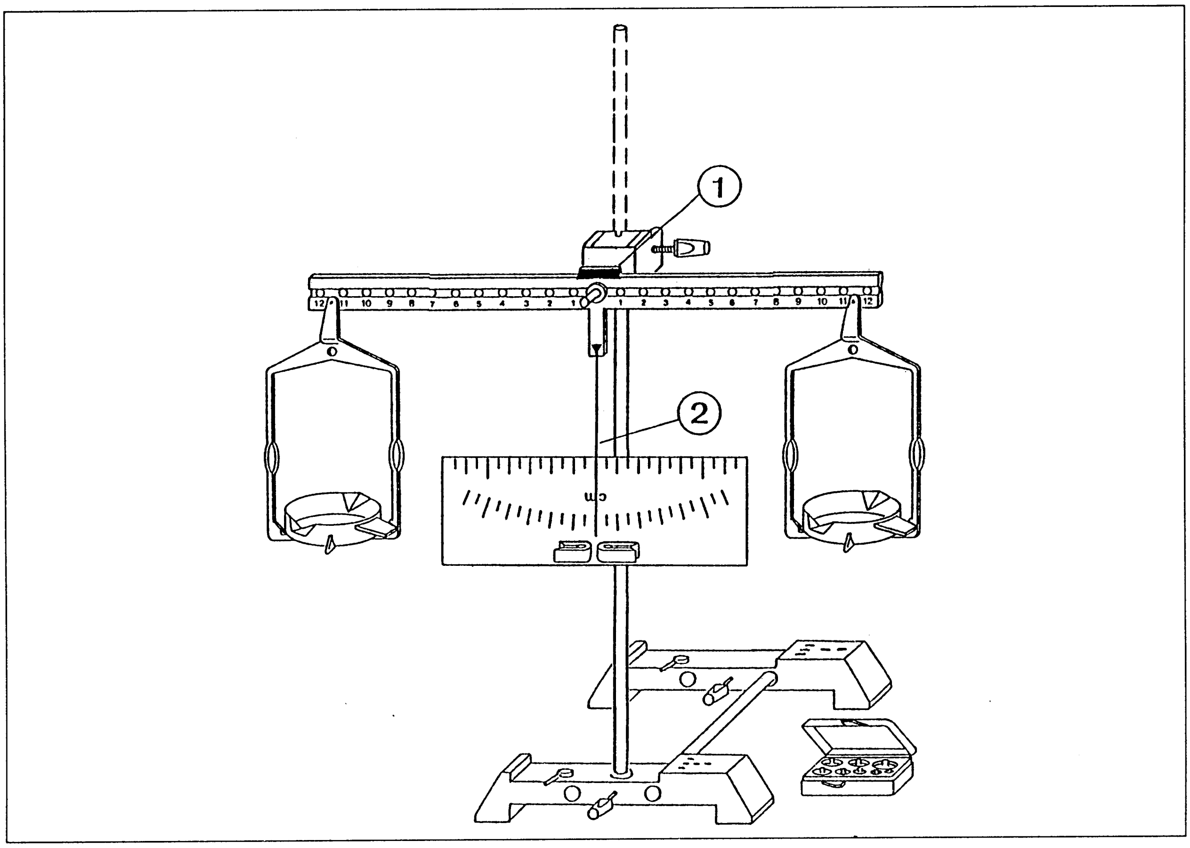


Fig. 1 Pair of scales
(1) balancing rider (taring weight)
(2) pointer

2. Fasten the first sleeve block to the middle of the stand rod and plug the spindle into the hole in its centre.
3. Attach the (metal) pointer to the lever with tip pointing upwards. It is held in place by a rubber stopper.
4. Fasten a sleeve block to the rod to hold the scale.

Student's Sheet 3

5. Attach the scale to the (lower) sleeve block with the help of two retaining clips. ▶ Fig. 2.
6. Position the lever on the spindle at its centre of rotation.

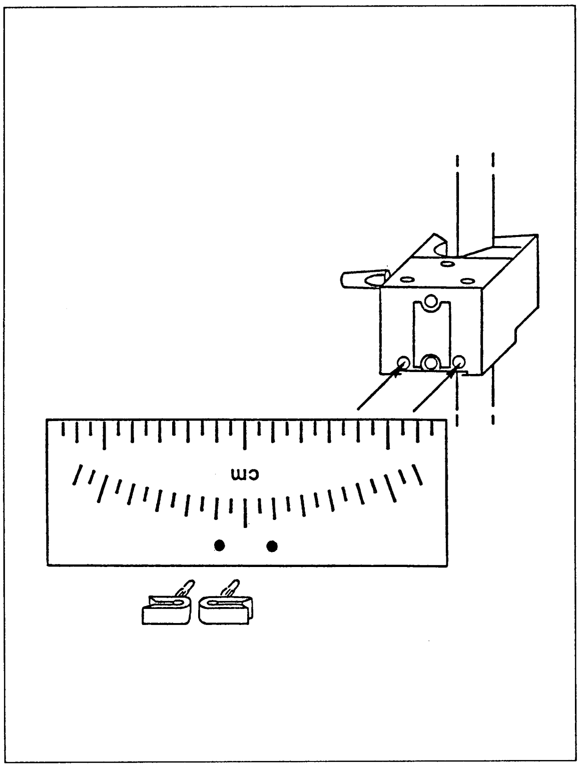


Fig. 2 Attaching the scale to the sleeve block using two retaining clips

7. Open the stirrups ▶ fig. 3 and insert the balançe pans.
8. Suspend the stirrups from the lever (between positions **(11)** and **(12)** on each side).
9. Slide the balancing rider **(1)** until the pointer **(2)** is pointing vertically downwards (to zero). Do not change the position of **(1)** from now on.

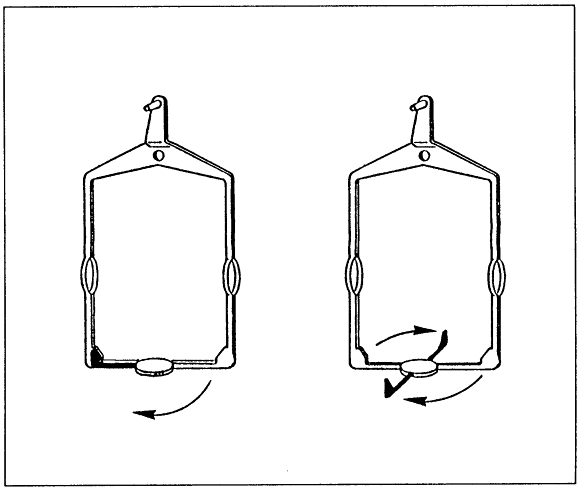


Fig. 3 Opening the stirrups

Student's Sheet 4

Performing the experiment:

10. Determine the mass of the objects listed in table 1.
Place the object to be weighed in the left-hand balance pan.
11. Restore the scales' equilibrium by placing weights from the set of weights in the right-hand balance pan, so that the pointer indicates "zero". If necessary, you may have to round the results up/down; to do this, you should remove/add the lightest weight available in the set and decide from the size of the deflection to left or right whether you should round the result up or down.
12. After you have finished with the weights, put them straight back in their storage box.

Observations and measurements:

Table 1

Object	Mass
Load hook	
Small pulley	
Large pulley	
Pair of pointers	

Evaluation:

13. How precisely can you measure mass using this pair of scales and the set of weights provided?

____

14. How would you measure the masses listed in the following table using the 1 g, 2 x 2 g, 5 g and 10 g weights from the set of weights? Complete the table by placing a cross below the weights you would use to measure each mass.

Table 2

Mass	1 g	2 g	2 g	5 g	10 g
1 g					
2 g					
3 g					
4 g					
5 g					
6 g					
7 g					
8 g					
9 g					
10 g					
11 g					
12 g					
13 g					
14 g					
15 g					

15. Intellectual exercise:

    9 weights appear to be identical, but one is heavier than the others. How can you find the heavier weight by making just two weighing tests?

One-sided lever

Assignment: To determine how the lever principle applies to one-sided levers.

Apparatus:

1 lever with pointer
1 knockout spindle
1 set of 6 weights
1 dynamometer, 1.5 N
1 dynamometer, 3 N
2 stand bases
1 stand rod, 25 cm
1 stand rod, 50 cm
1 sleeve block

Student's Sheet 2

Setup:

1. Assemble the stand bases and stand rods as shown in fig. 1.

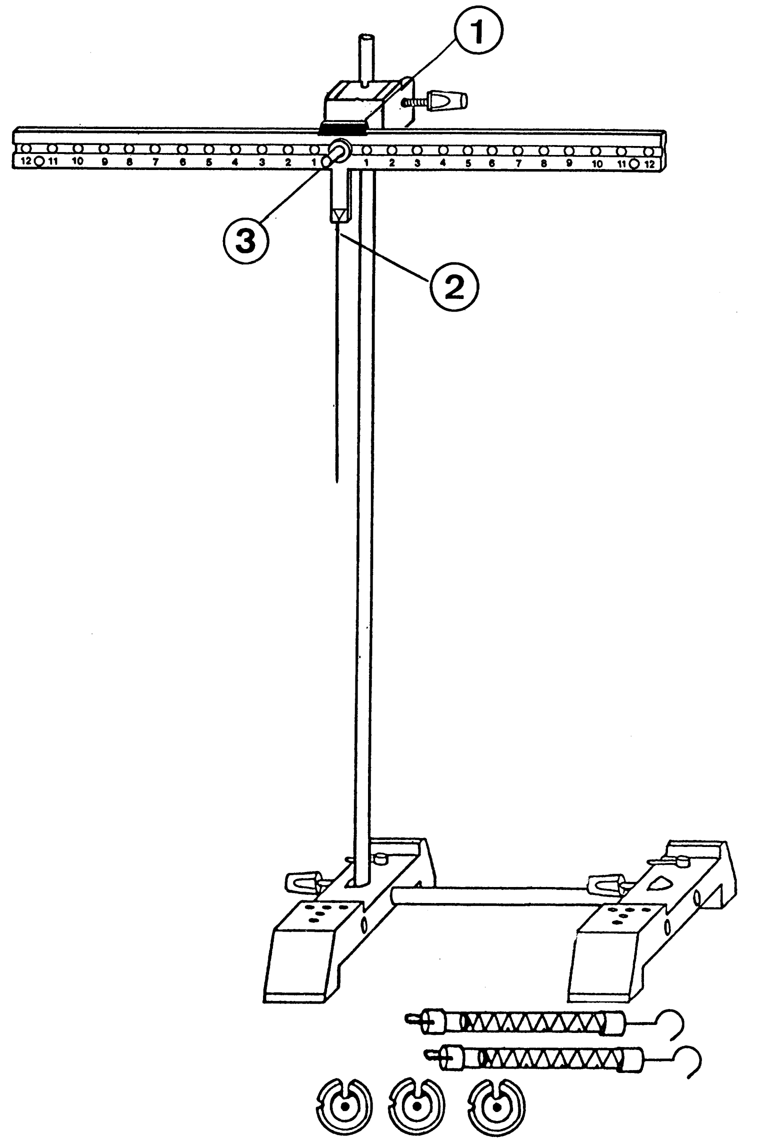


Fig. 1 Setup for experiments using a two-sided lever
(1) Balancing rider (taring weight) **(2)** Pointer **(3)** Spindle

2. Fasten the sleeve block in place in the top third of the vertical stand rod.
3. Plug the knockout spindle into the centre hole in the sleeve block.
4. Place the lever on the spindle at its point of rotation.
5. Slide the balancing rider **(1)** along the lever until the pointer **(2)** is pointing vertically downwards (at zero).

Student's Sheet 3

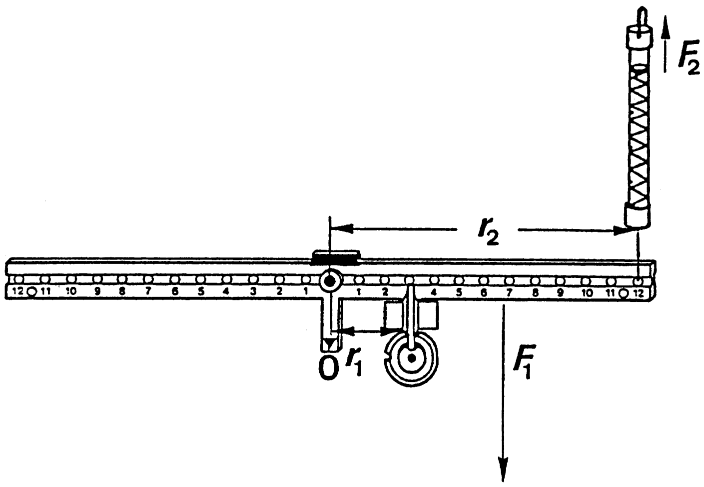


Fig. 2 Forces and loads acting on a one-sided lever
F_1: load r_1: work arm
F_2: force r_2: power arm

Experiment part 1:
Force where load is constant, power arm is constant and work arm is variable

6. Suspend two weights F_1 = 1.0 N from position 3 (r_1 = 4.5 cm). Hold the lever steady!
7. Hook the dynamometer to the same side of the lever, at position 12 (r_2 = 18 cm).
8. Pull the dynamometer vertically upwards until the pointer is once again indicating "zero"
9. Take a reading for the force required F_2 from the dynamometer. Enter the reading ▶ Table 1
10. Move the weights to position 6 (r_1 = 9 cm). Repeat the measurement. Enter the new reading ▶ Table 1
11. Move the weights to position 12 (r_1 = 18 cm). Take measurements as before. Enter the reading ▶ Table 1

Experiment part 2:
Force where work arm and power arm are constant and load is variable

12. Suspend 1, 2 and 3 weights from position 6 (r_1 = 9 cm) one after the other, repeating steps 8 and 9 every time you add a weight.

Experiment part 3:
Force where load is constant and work arm is constant, but power arm is variable

13. Suspend a weight F_1 = 0.5 N from position 12 (r_1 = 18 cm) and measure the force at the following positions:
(3, r_2 = 4.5 cm)
(6, r_2 = 9 cm)
(12, r_2 = 18 cm)
Enter the values measured ▶ Tabelle 1

Table 1

Variable	Unit	Experiment part 1			Experiment part 2			Experiment part 3		
No. of weights	–	2	2	2	1	2	3	1	1	1
Load F_1	N	1.0	1.0	1.0	0.5	1.0	1.5	0.5	0.5	0.5
Work arm r_1	cm	*4.5*	*9*	*18*	9	9	9	18	18	18
Force F_2	N									
Power arm r_2	cm	18	18	18	18	18	18			
$F_1 \cdot r_1$	N cm									
$F_2 \cdot r_2$	N cm									

Evaluation:

14. Complete the last two lines in table 1.
What conditions must be satisfied if the lever is to remain in equilibrium?

____

____

____

____

15. Complete the following table:
Table 2:

Load	constant	greater	constant
Work arm	greater	constant	constant
Power arm	constant	constant	greater
Force			

16. How do one-sided levers differ from two-sided levers?

____

____

____

17. Name some examples of applications for one-sided levers.

1.2.5.4

Shaft-mounted wheel

Assignment:

- To put together a shaft-mounted wheel consisting of one small and one large pulley.
- To investigate the lever principle as applied to the shaft-mounted wheel.

Apparatus:

1 pulley, 5 cm ⌀
1 pulley, 10 cm ⌀
1 knockout spindle (crank)
1 coupler plug
1 set of 6 weights
1 dynamometer, 1.5 N
2 stand bases
1 stand rod, 25 cm
1 stand rod, 50 cm
1 sleeve block
1 cord, 40 cm

in addition:
1 pair of scissors

Student's Sheet 2

Setup:

1. Set up the apparatus as shown in fig. 1.
2. Attach a weight to the small pulley by a fishing line, as shown in fig. 1.
3. Plug the coupler plug **(1)** into one of the outer holes in the small pulley and connect the large pulley to the small pulley using the two coupler plugs protruding from both pulleys.

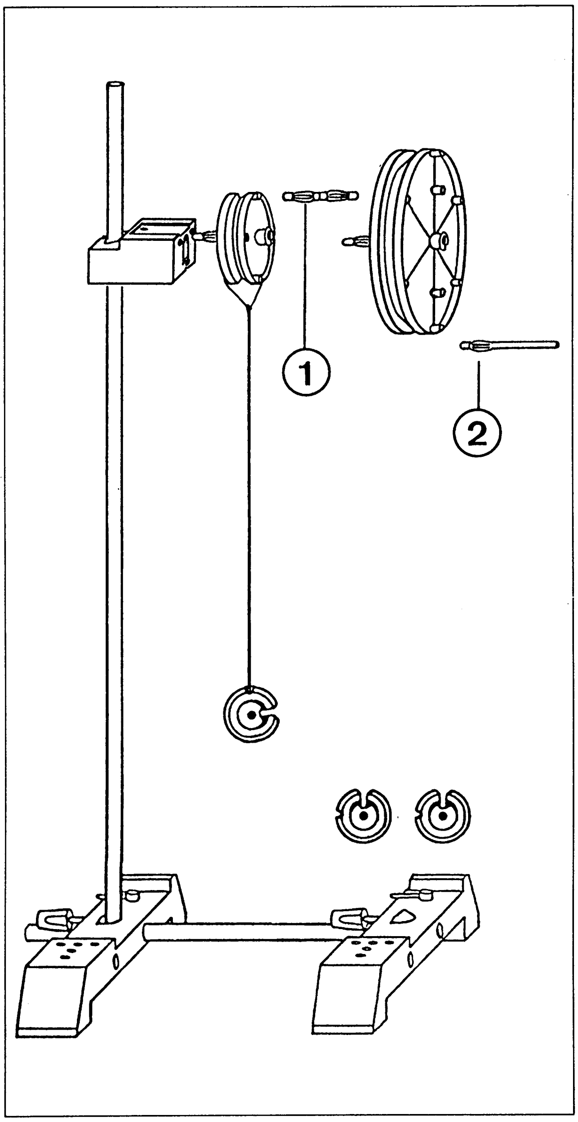


Fig. 1 Instructions for setting up a shaft-mounted wheel
(1) Coupler plug for connecting the two pulleys together
(2) Knockout spindle acting as a crank handle (attached to the outer face of the large pulley)

Performing the experiment:

4. Using the crank handle, turn the shaft-mounted wheel so that the weight (F_1 = 0.5 N) is lifted off the bench.

   Caution:

   The cord should run through the groove in the small pulley.
5. Suspend the dynamometer from the crank handle.
6. Measure the force F_1 required to maintain equilibrium.
   Enter your reading ▶ Table.
7. Determine the length of the power arm r_1
   (r_1 = radius of the small pulley
   = half the diameter of the small pulley).
8. Determine the length of power arm r_2
   (radius of the large pulley).
9. Repeat steps 5 and 6
   a) using two weights
   b) using three weights.
   ▶ Table

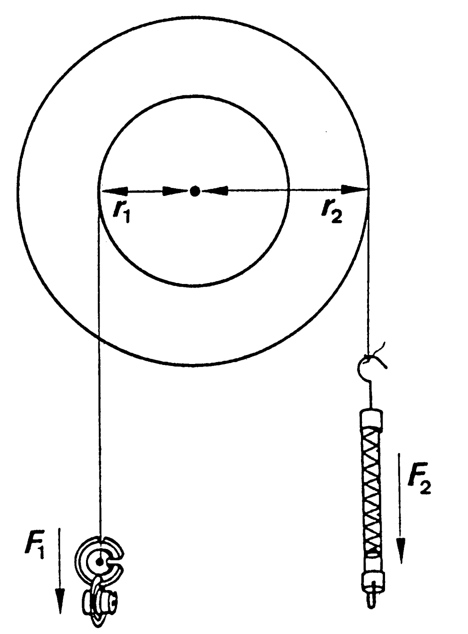


Fig. 2 Shaft-mounted wheel (schematic diagram)
r_1 : radius of small pulley
r_2 : radius of large pulley
F_1 : force exerted by load
F_2 : force acting on power arm

Table

Number of weights n	–	1	2	3
Load F_1	N	0.5	1.0	1.5
Work arm r_1	cm			
Force F_2	N			
Power arm r_2	cm			
$F_1 \cdot r_1$	N cm			
$F_2 \cdot r_2$	N cm			

Student's Sheet 4

Evaluation:

10. Calculate $F_1 \cdot r_1$ and $F_2 \cdot r_2$
Compare the results.

11. Give some examples of applications for shaft-mounted wheels.

Student's Sheet 1

Belt-driven gearing

Assignment:

- To construct a belt-driven gear unit (transmission).
- To determine the direction of rotation of the transmission.
- To determine the step-up/step-down gearing of the transmission.

Apparatus:

1 pulley, 5 cm ⌀
1 pulley, 10 cm ⌀
1 plug-in spindle (crank)
1 rubber ring
2 stand bases
1 stand rod, 25 cm
1 coupler plug

Setup:

1. Set up the apparatus as shown in fig. 1.
2. Clamp the stand bases to the stand rod, as far apart as possible.
3. Plug the pulleys (gearwheels) into the centre holes in the stand bases ▶ Fig. 1.
4. Insert the coupler plug and spindle as shown in fig. 1.

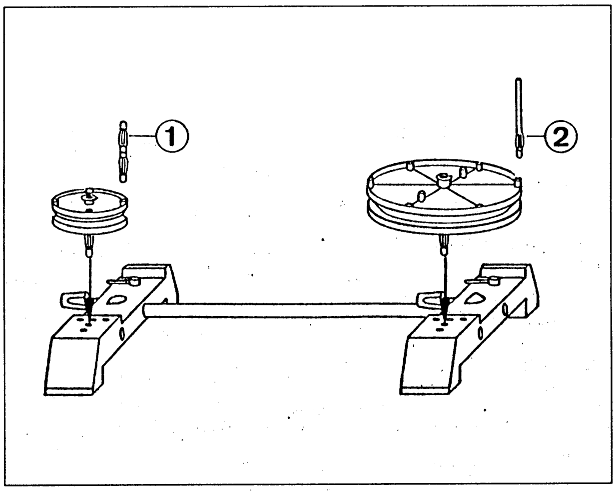


Fig. 1 How to assemble a belt-driven transmission:
(1) Coupler plug fitted as crank handle and indicator
(2) Plug-in spindle fitted as crank handle and indicator

Student's Sheet 2

Performing the experiment:

Experiment part 1:
Transmission with uncrossed transmission belt

5. Fit the transmission belt (rubber ring) into the grooves of the two wheels, as shown in fig. 2.

6. To compare the direction in which the two wheels are rotating, observe the knockout spindle.

   ▶ **(1)** in fig. 2

7. Use the crank handle to turn the larger wheel in a clockwise direction.

   ▶ Arrow in fig. 2.

   Which way does the smaller wheel turn?

   ____

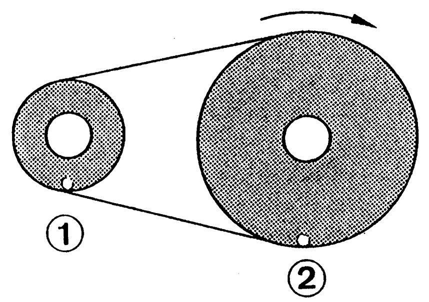


Fig. 2 Transmission with uncrossed transmission belt
(1) Coupler plug
(2) Plug-in spindle

8. How many times n_1 does the smaller wheel rotate whenever the big wheel makes one complete revolution?

   ____

9. How many times n_2 does the larger wheel rotate whenever the small wheel makes one complete revolution?

   ____

Experiment part 2:
Transmission with crossed transmission belt

10. Fit the transmission belt round the wheels as shown in fig. 3.

    Use the crank handle to turn the larger wheel clockwise.

    ▶ Arrow in fig. 3.

    Which way does the small wheel rotate?

    ____

11. Repeat steps 8 and 9.

    Does the number of revolutions completed by both wheels change because the belt is crossed?

    ____

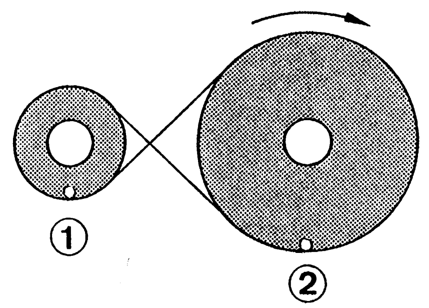


Fig. 3 Transmission with crossed transmission belt
(1) Coupler plug **(2)** Plug-in spindle

Evaluation:

12. The driving belt in a gear unit (transmission) is crossed.

    How does the relationship between the driving and the driven wheel change?

    ____

    ____

13. Express the number of revolutions completed by each wheel as a ratio in terms of their respective diameters.

    Designations:

    d_1 = diameter of the smaller wheel
    d_2 = diameter of the larger wheel
    n_1 = number of revolutions completed by smaller wheel
    n_2 = number of revolutions completed by larger wheel

    $d_1 : d_2$ = __ mm : __ mm = ____

    $n_1 : n_2$ =

    $d_2 : d_1$ = mm : _ mm = ____

    $n_2 : n_1$ =

    Complete the following statement:

    The number of revolutions completed by the gears is in ____________ to the diameter of the wheels.

14. We talk about *stepped-down gearing* if the number of revolutions completed by the driven wheel is fewer than the number of revolutions completed by the driving wheel.

    What is the reduction in speed produced by the gearing in fig. 1?

    ____

15. Complete the following sentence:

    We talk about *stepped-up gearing* if the number of revolutions completed by the driven wheel is ________ than the number of revolutions completed by the driving wheel.

    What is the increase in speed produced by the gearing in fig. 1?

    ____

Fixed pulley

Assignment:

- To lift a load to a given height using a fixed pulley.
- To determine the force required.
- To compare the distance moved by load and distance moved by force.

Apparatus:

1 pulley, 5 cm ∅
1 dynamometer, 1.5 N
3 weights
1 cord (ca. 50 cm)
1 sleeve block
1 stand rod, 50 cm
1 stand rod, 25 cm
2 stand bases

in addition:
1 pair of scissors

Student's Sheet 2

Setup:

1. Assemble the stand bases, stand rods and sleeve as shown in fig. 1.
2. Plug the spindle and pulley into the central hole in the sleeve block.
3. Position the pointer in such a way that it points forwards at an angle.
4. Fasten the cord to the weight. Tie a loop at the other end and hook it to the dynamometer.

   Do not place the cord over the pulley just yet.

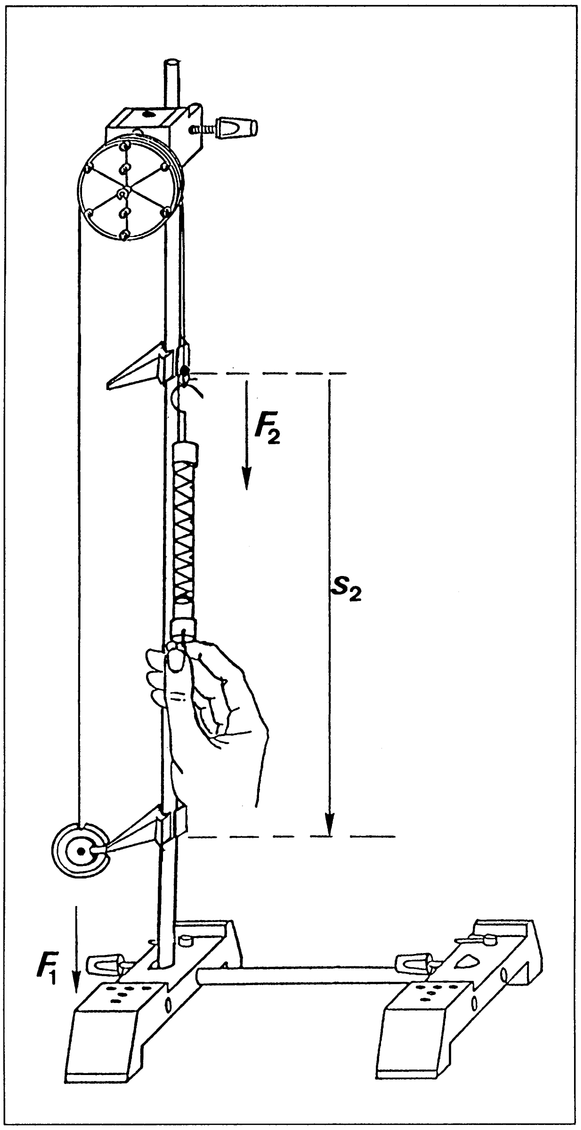


Fig. 1 Experimental setup: fixed pulley

Performing the experiment:

5. Determine the force due to weight exerted by the weight. ▶ Fig. 2 $F_1 \approx$ ____
6. In which direction is the force due to weight F_1 exerted?

____

7. In which direction does the force F_2 exerted by the dynamometer act on the weight?

____

8 Compare F_1 and F_2.

____

____

____

9. Place the cord over the pulley. Does the force F_2 indicated by the dynamometer change
   a) direction? ___
   b) magnitude? ___

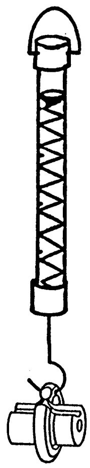


Fig. 2 Weight attached to dynamometer

10. As illustrated in fig. 1, position the lower pointer so that it is pointing at the centre of the weight and the upper pointer so that it is pointing at the knot of the loop to which the dynamometer is attached.
    How far (over what distance moved by load s_1) is the weight lifted if you pull the knot downwards as far as the lower pointer (through a distance moved by force s_2)? Remove the dynamometer!

____

11. Compare the distance moved by the load s_1 and the distance moved by force s_2 with one another.

____

Evaluation:

12. Does the fixed pulley reduce force?

____

13. Does the fixed pulley reduce distance?

____

14. What are the advantages of using a fixed pulley?

____

____

Student's Sheet 1

Movable pulley

Assignment:

- To lift a load F_1 to a given height using a movable pulley.
- To determine the force F_2 required.
- To compare the distance moved by load s_1 and distance moved by force s_2.

Apparatus:

1 pulley, 5 cm ⌀
1 load hook
3 weights
1 pair of pointers
1 dynamometer, 1.5 N
1 retaining clip
1 tape measure, 1.5 m
2 sleeve blocks
2 stand rods, 50 cm
1 stand rods, 25 cm
2 stand bases
1 cord (ca. 40 cm)

in addition:
1 pair of scissors

Student's Sheet 2

Setup:

1. Set up the apparatus as shown in fig. 1.
2. Fasten the sleeve blocks roughly in the middle of the stand rods. Clamp the pointers to the lower end of one rod. Position the pointers so that they point diagonally forwards.
3. Tie a knot at one end of the cord and a loop at the other end.
4. Wedge the knot in the hole provided in the left-hand sleeve block.
5. Clamp the dynamometer in the retaining clip and hook it to the loop in the cord.
6. Plug the load hook into the pulley's central axle.
7. Hang the weight from the load hook.
8. Place the pulley in the cord as shown.
9. Set the lower pointer so that it is indicating the bottom edge of the weight, and the upper pointer just 2 cm above it.

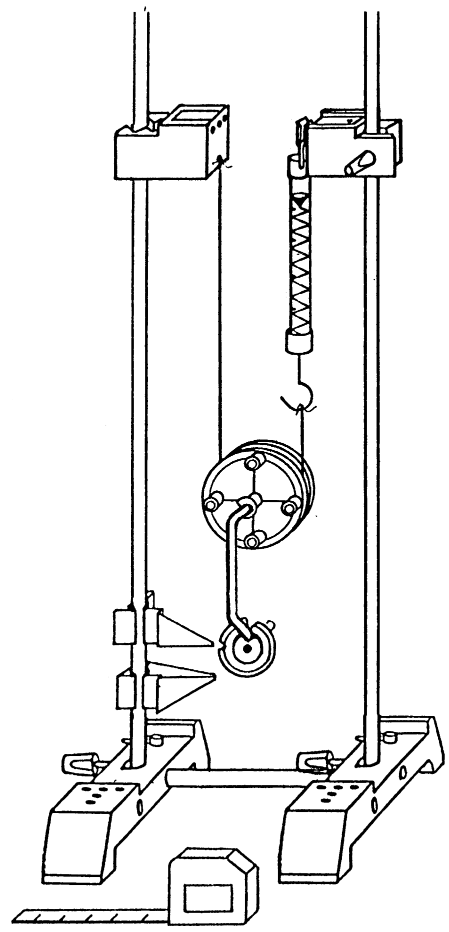


Fig. 1 Experimental setup: movable pulley

Performing the experiment:

10. Note the height x_0 of the underside of the dynamometer above the workbench surface. (Initial position x_0)
11. Lift the load through the distance moved by load s_1.
    (Move the right-hand sleeve block until the lower edge of the weight reaches the topmost pointer).
12. What is the force required to do this?
    Enter your reading in table 1.
13. Make a note of the dynamometer's final position (height of the dynamometer's underside above the workbench surface) in table 1.
14. Repeat the experiment with the loads and distances listed in table 1.

    If the right-hand stand rod is not long enough for you to move the sleeve block upwards by the necessary distance, then you should slide the left-hand sleeve block higher up the left-hand stand rod.

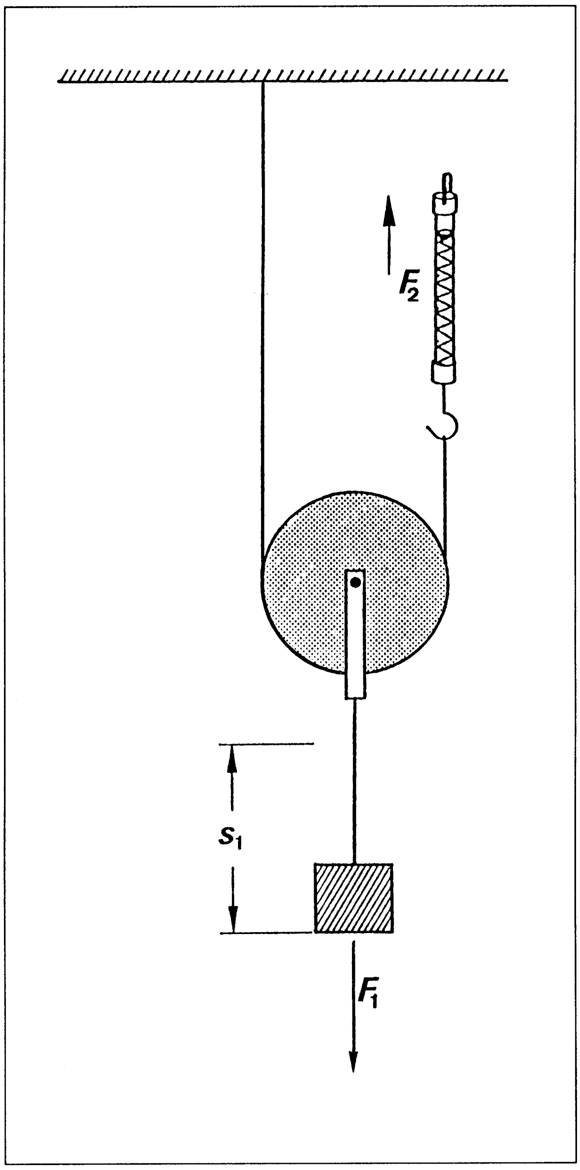


Fig. 2 Sketch: movable pulley
s_1 = distance moved by load
F_1 = force due to weight
F_2 = force (dynamometer's elastic force)

Student's Sheet 4

Observations and measurements:

Hint:

The load as a whole is composed of pulley, load hook and weights.

Table 1

15.

Load	F_1	0.82 N	1.31 N	1.80 N
Distance moved by load	s_1			
Force	F_2			
Initial position	x_0			
Final position	x_1			
Distance moved by force	s_2			
$F_1 \cdot s_1$				
$F_1 \cdot s_2$				

Evaluation:

16. Calculate the distance moved by force $s_2 = x_1 - x_0$ and enter the result in table 1.
17. Calculate $F_1 \cdot s_1$ and $F_2 \cdot s_2$ and enter the result in table 1.
18. Does the use of a movable pulley reduce the force required?

____

19. What is the relationship between the distance moved by force and the distance moved by load?

____

20. The result of the equation "force x distance moved by force" or "load x distance moved by load" is known as work. If you use a movable pulley, the work on the side of the load is ______ to the work performed on the side of the force:

load x distance moved by load = force x ____________________

Work gained = ________ expended.

Hoist with two pulleys

Assignment: To build a hoist out of movable and fixed pulleys.

Apparatus:

2 pulleys, 5 cm
2 retaining clips
1 load hook
4 weights
1 dynamometer, 3 N
2 sleeve blocks
1 stand rod, 25 cm
1 stand rod, 50 cm
2 stand bases
1 cord (ca. 90 cm)

in addition:
1 pair of scissors

Student's Sheet 2

Setup:

1. Assemble the stand bases, stand rods and sleeve blocks as shown in fig. 1.

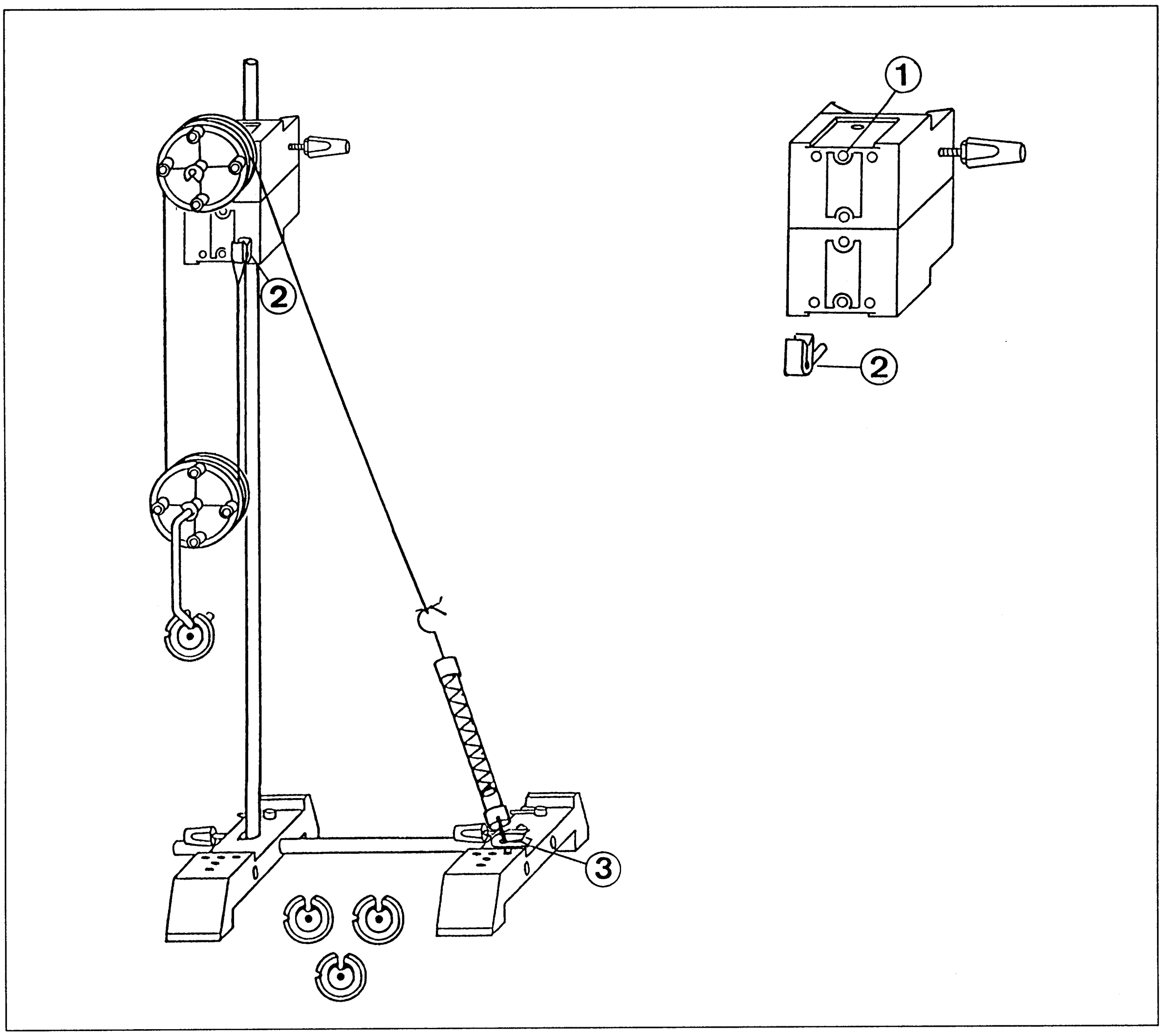


Fig. 1 Load hoist with one movable pulley and one fixed pulley.
Inset diagram:
Arrangement of the two sleeve blocks on the stand rod
(1) Hole for plugging in the fixed pulley; **(2)** and **(3)** retaining clips

2. Tie a loop at both ends of the cord (yarn).
3. Arrange the sleeve blocks as shown in the drawing inset in fig. 1.
4. Plug the fixed pulley into hole **(1)**.
5. Insert the load hook into the movable pulley's central axle.

Table

Number of weights	0	1	2	3	4
Load F_1					
Force F_2					

6. Establish the load (weight) F_1 which results if you add 0, 1, 2, 3, 4 weights to the movable pulley (the pulley with the load hook).

   Enter the measurements ▶ Table.
7. Hook the cord to the retaining clip **(2)** and position it round the pulleys. ▶ Fig. 1.
8. Hook the dynamometer to the yarn. Measure the forces required to lift the loads specified in the table on the cord.

Evaluation:

9. Describe how the two pulleys work.

____

____

Student's Sheet 1

Block and tackle 1 (open type)

Assignment

- To construct a block and tackle from movable and fixed pulleys (also termed "loose" and "fast" pulleys).
- To investigate the conditions required to bring about an equilibrium of forces.

Apparatus:

2 pulleys, 10 cm ⌀
2 pulleys, 5 cm ⌀
2 pulley bridges
1 load hook
1 coupler plug
1 knockout spindle
2 retaining clips
1 dynamometer, 1.5 N
1 pair of pointers
3 weights
2 stand bases
2 stand rods, 50 cm
1 stand rods, 25 cm
2 sleeve blocks
1 universal socket
1 tape measure, 1.5 cm
1 cord (ca. 280 cm)
in addition:
1 pair of scissors

Student's Sheet 2

Setup:

1. Assemble the parts of the stand as shown in fig. 1.

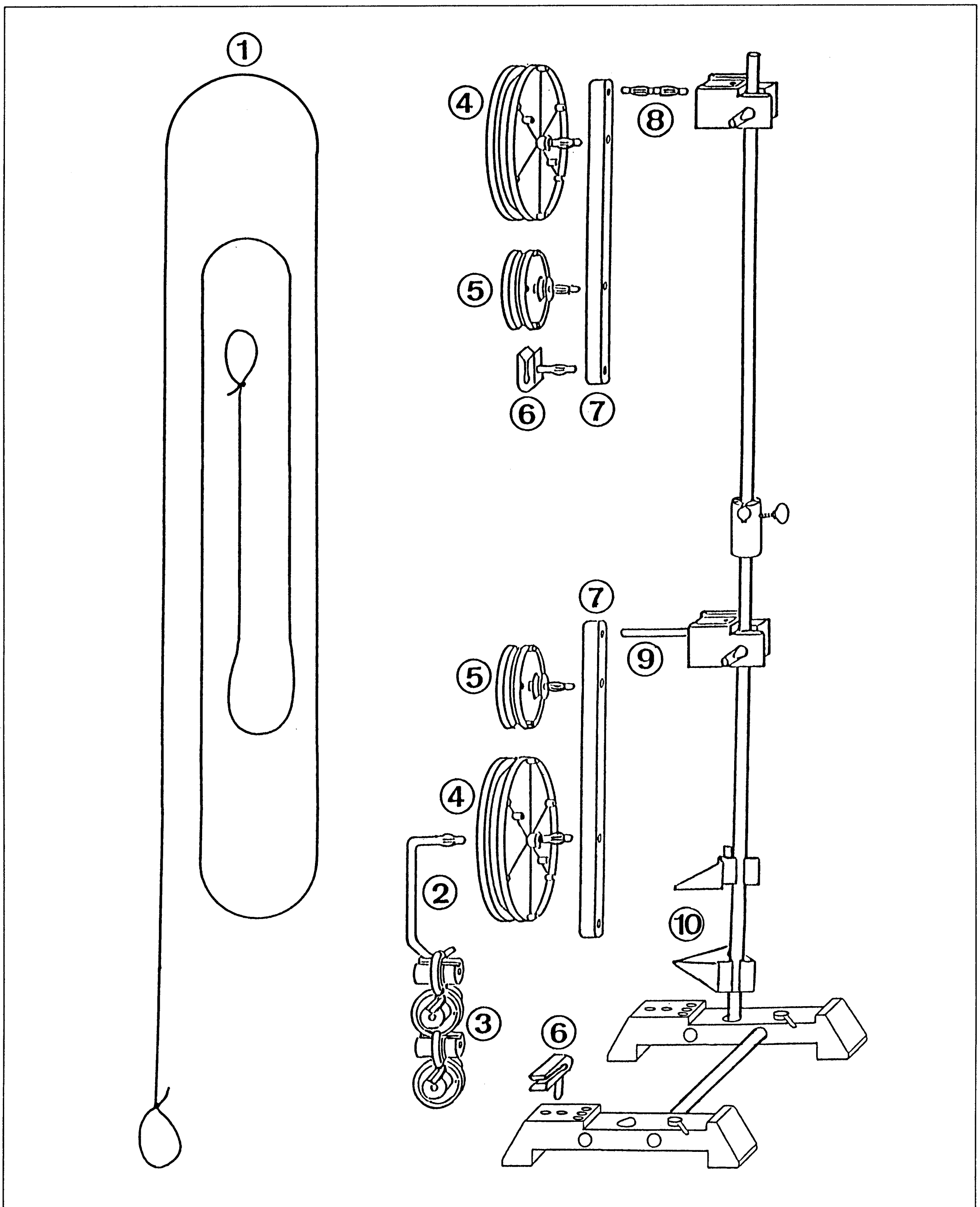


Fig. 2 Instructions for setting up a block and tackle with 4 pulleys
(1) Cord (ca. 250 cm) with loops at both ends
(2) Load hook
(3) Weights
(4) Large pulley
(5) Small pulley
(6) Retaining clip
(7) Pulley bridge
(8) Coupler plug
(9) Knockout spindle
(10) Pointers

Student's Sheet 3

2. Tie a loop at both ends of the cord.
3. Plug a retaining clip into one of the holes in the stand base.
4. Attach one large and one small pulley to each of the two pulley bridges, as shown in fig. 1.
5. Insert the coupler plug into the top sleeve block and the knockout spindle into the bottom one.
6. *Note:*
   The lower sleeve block is used as a construction aid – you should remove it later on.
7. Attach a retaining clip to one of the pulley bridges, under the smaller pulley.
8. Attach this pulley bridge to the coupler plug in the higher sleeve block, with the larger pulley at the top.
9. Attach the load hook to the large pulley on the other pulley bridge.
10. Position this pulley bridge on the spindle plugged into the lower sleeve block, with the smaller pulley at the top.
11. Attach the cord to the retaining clip on the stand base and wind it round the pulleys as shown in fig. 2.
12. Fasten the dynamometer to the retaining clip in the stand base and hook it to the loop at the end of the cord.
    If necessary, move the lower sleeve block until the dynamometer is placed under tension.
13. Hang a weight from the load hook.
14. Carefully remove the lower pulley bridge from the spindle and remove the auxiliary sleeve block (with the spindle) from the assembly.

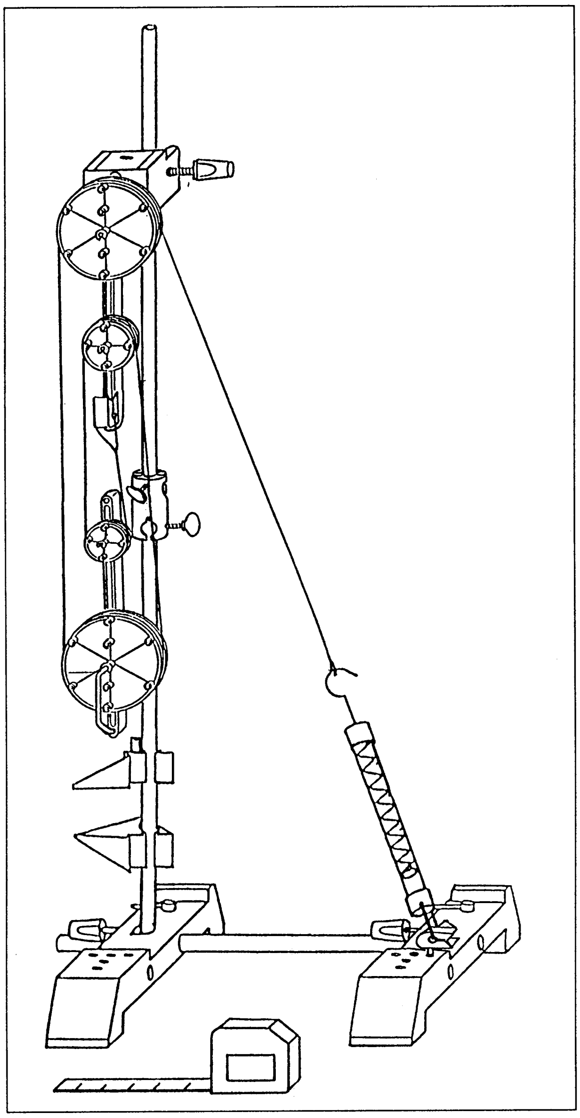


Fig. 3 Block and tackle with four pulleys

Performing the experiment:

15. Position the lower pointer about 5 cm above the stand base, and the higher pointer about 2 cm above it.
16. Take the dynamometer off its retaining clip and lower the weight to the level of the lower pointer.
    Make sure that the centre of the weight or its lateral indentation are positioned at the same level as the pointer.
17. Determine the height x_0 of the dynamometer above the workbench surface. Enter it ▶ Table.
18. Raise the load by the distance s_1 shown in the table.
    What force F_2 is required to do this? Note it down ▶ Table.

Student's Sheet 4

19. Measure the height x_1 of the dynamometer above the surface of the workbench and note it down ▶ Table.

20. Repeat the experiment with the loads and distances travelled by loads specified in the table.

Observations and measurements:

Table

21.

Load	F_1	1.2 N	1.7 N	2.2 N
Distance moved by load	s_1	2.0 cm	3.0 cm	4.0 cm
Force	F_2			
Starting position	x_0			
Final position	x_1			
Distance moved by force	s_2			

Evaluation:

22. What is the ratio of the load F_1 to the force required F_2?

____

18. What is the ratio of the distance moved by load s_1 to the distance moved by force s_2?

____

19. A block and tackle with 2 movable pulleys is in equilibrium if the force F_2 equals __________ of the load F_1:

____

Block and tackle 2 (compact version)

Assignment:

- To construct a compact block and tackle from movable and fixed pulleys (also termed "loose" and "fast" pulleys).
- To determine the right conditions for comparing forces.

Apparatus:

2 pulleys, 5 cm ∅
2 pulleys, 10 cm ∅
1 load hook
1 pulley bridge
1 coupler plug
1 set of 6 weights
1 retaining clip
1 cord (ca. 150 cm)
1 tape measure, 1.5 m/1 mm
2 stand bases
1 stand rod, 25 cm
1 stand rod, 50 cm
1 sleeve blocks
1 dynamometer, 1.5 N

in addition:
1 pair of scissors

Student's Sheet 2

Setup:

1. Assemble the parts as shown in fig. 1:

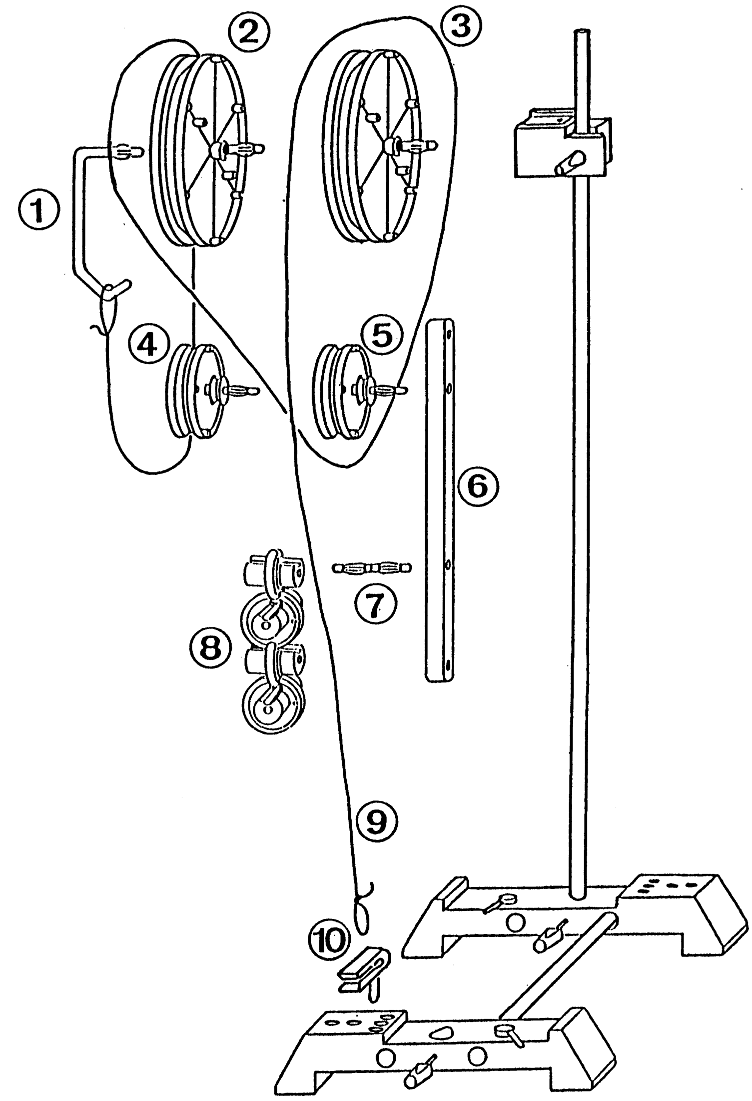


Fig. 1 Setup: compact block and tackle
(1) Load hook
(2)–(5) Pulleys
(6) Pulley bridge
(7) Coupler plug
(8) Weights
(9) Cord (1.5 m) with loops tied at either end
(10) Retaining clip

2. Tie a loop at each end of the cord **(9)**.
3. Plug the retaining clip **(10)** into one of the holes in the stand base.

Student's Sheet 3

4. Plug in:
   (1) to **(2)**; **(2)** to **(3)**; **(3)** to the centre hole in the sleeve block.
   (4) to **(5)**; **(5)** to the second hole in the pulley bridge; **(7)** to the third hole in the pulley bridge; **(8)** to **(7)**.
5. Attach one loop of the cord to **(1)**, then wind it clockwise around pulley **(4)**.
6. Then continue to wind the cord (clockwise) around **(2)**.

   This results in a block and tackle with two pulleys.
7. If you continue to wind the cord round pulleys **(5)** and **(3)**, the result is a block and tackle with 4 pulleys.
8. Attach the other loop to the retaining clip **(10)**.

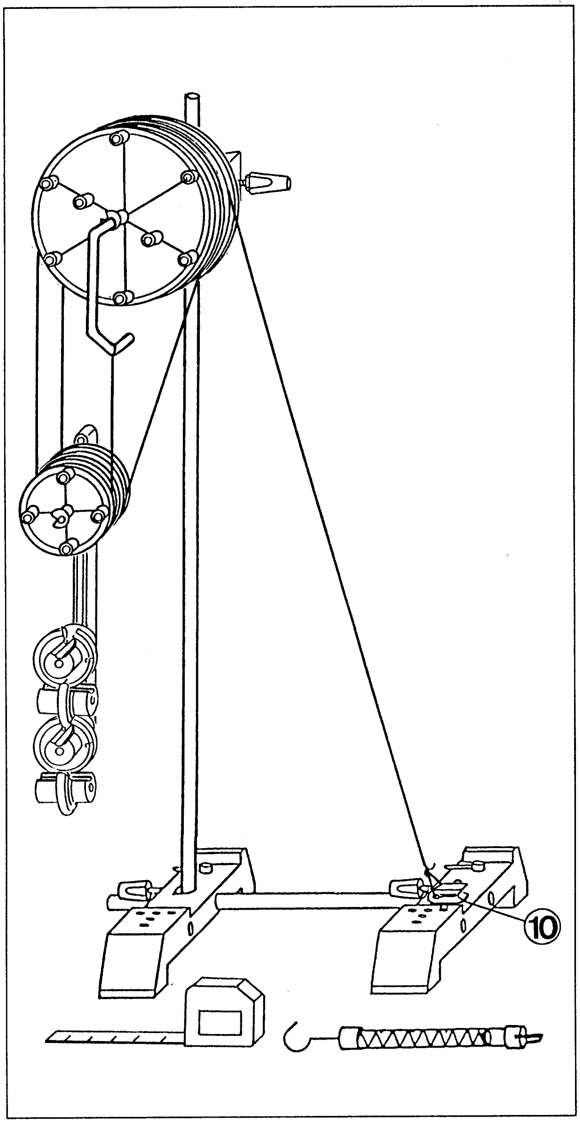


Fig. 2 Setup: "Compact block and tackle".
(10) Retaining clip

Performing the experiment:

9. Determine how many centimeters away from the structure you must pull the cord (distance moved by force) in order to lift the load by a distance of s_1 = 5 cm.

   Distance moved by force s_2 = _____
10. What force F_2 is required to hold the load in place?

   F_2 = ____

Evaluation:

11. How many separate sections of cord is the load hanging from?

____

12. What is the force the load is exerting on each of these sections of cord?

____

13. So how great is the force F_1 exerted by the load?

____

____

14. Determine the force due to weight F_1 with the help of the dynamometer.
    Compare the result with step 13.
    3 weights weigh approximately _____
    Coupler plug, pulley bridge, weights and two small pulleys combined all weigh ca. _____

____

____

____

15. Compare:
    $F_1 \cdot s_1 =$ ________________

    $F_2 \cdot s_2 =$ ________________

    Formulate the resultant equation:

____

Student's Sheet 5

Note:

The compact version of this block and tackle represents the way a traditional block and tackle is constructed. In the latter case, fixed and movable pulleys are held in frames. The design of "block and tackle 1" takes up too much room.

Frequently, the differential chain block is used instead of the conventional block and tackle.

▶ Fig. 4.

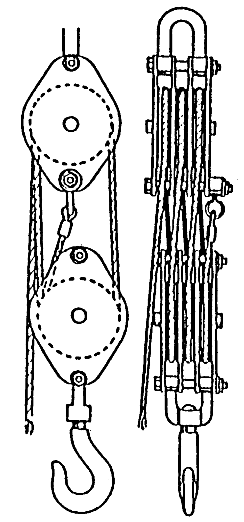


Fig. 3 Block and tackle: compact industrial version

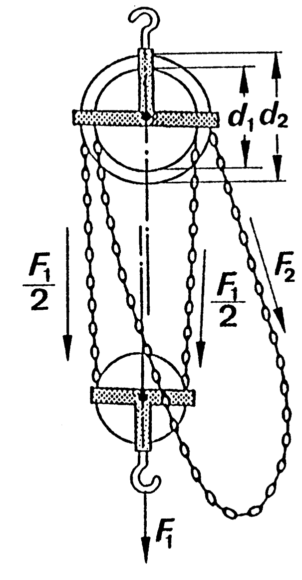


Fig. 4 Differential chain block
The two pulleys with diameters d_1 and d_2 are firmly linked together by their centre pivots.

Forces acting on an inclined plane

Assignment: To investigate downward force on a slope consisting of an inclined plane, when the plane is inclined at a variety of angles (gradients)

Apparatus:

1 inclined plane
1 knockout spindle
2 pulleys, 5 cm ⌀
1 coupler plug
1 dynamometer, 1.5 N
2 weights
1 sleeve block
2 stand bases
1 stand rod, 50 cm
1 stand rod, 25 cm
1 tape measure

Setup:

1. Assemble the stand bases, stand rods and universal sleeve. ▶ Fig. 1

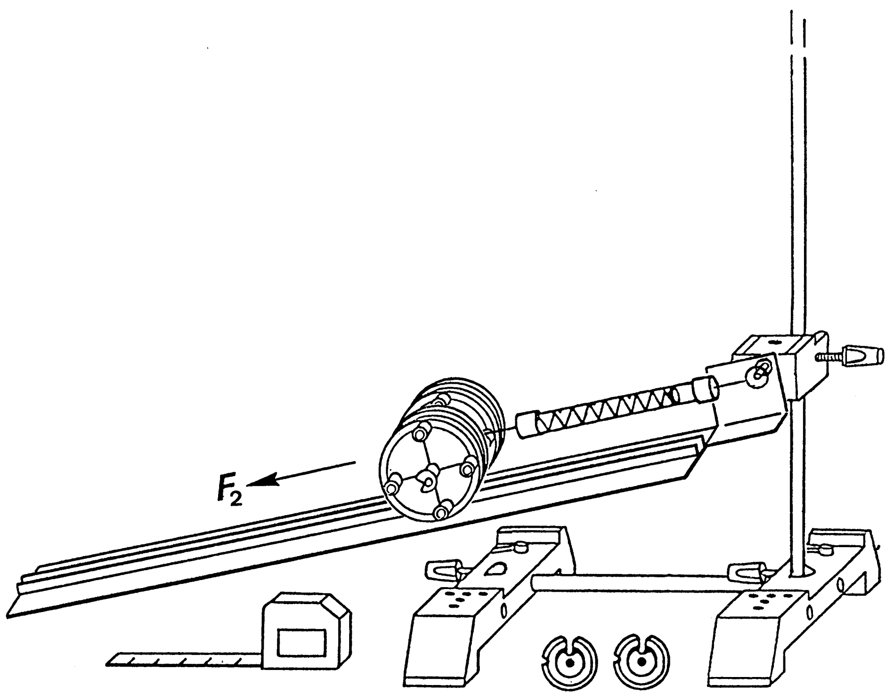


Fig. 1 Inclined plane: measuring downward force due to slope F_2

Student's Sheet 2

2. Insert the spindle into a hole in the sleeve block and suspend the inclined plane from it.
3. Fasten the two pulleys together using the connector plug.
   ▶ Fig. 2
   You attach the weights **(3)** at a later stage.

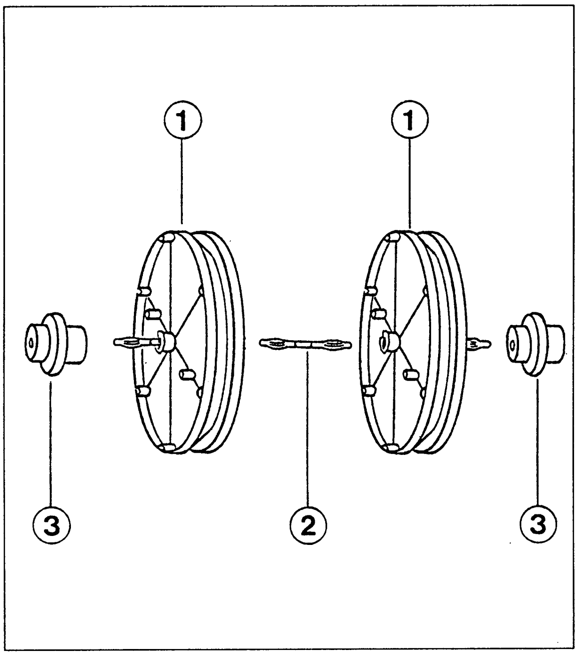


Fig. 2 Plugging together two pulleys **(1)** using a coupler plug **(2)**, **(3)** weight

Performing the experiment:

4. Measure the length of the inclined plane.
   Enter the measurement ▶ Table.
5. Determine the force due to weight F_1 exerted by the pair of pulleys.
6. Place the pair of pulleys on the inclined plane and fix them in place by the dynamometer attached to the coupler pin.
   ▶ Fig. 1 / Fig. 3.

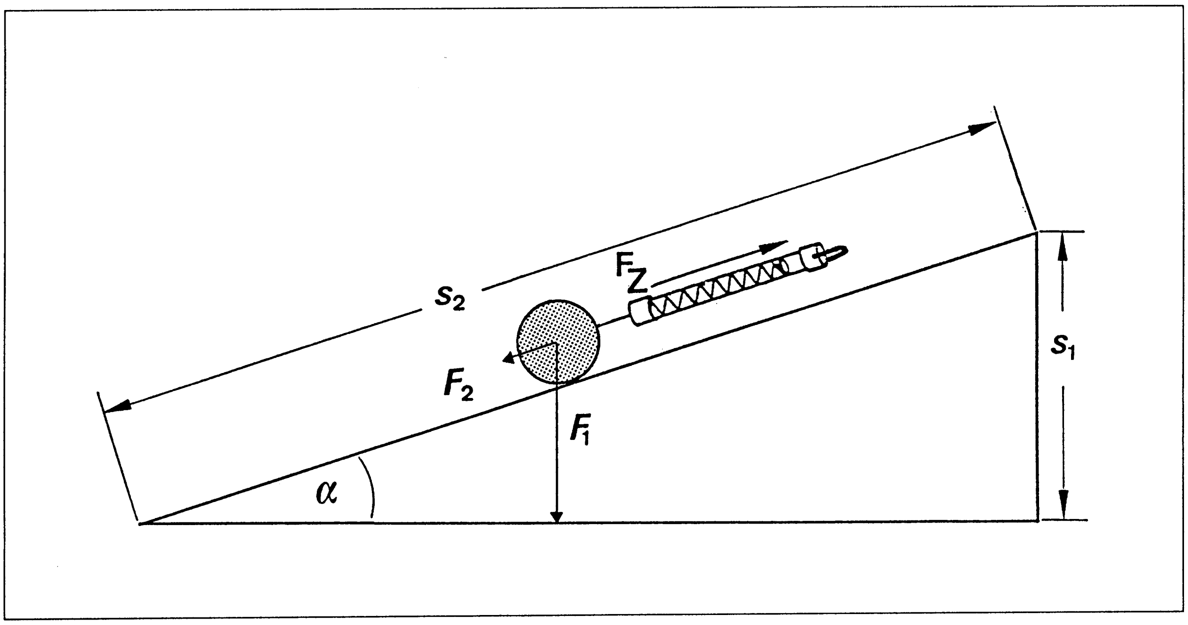


Fig. 3 Distances and forces at work on an inclined plane
s_1 : height, s_2 = length, F_1 : weight of the load, F_2 = downward force due to slope

Student's Sheet 3

7. Use the tape measure to help you move the inclined plane to the heights s_1 listed in the table. Then measure the downward force due to slope F_2 in each case.
   Enter your measurements ▶ Table
8. Attach the two weights to the pulleys' axes. ▶ Fig. 2.
   Repeat step 7. ▶ Table.

Table

Length of the inclined plane: $s_2 = 40\ cm$				
Force due to weight F_1	Height s_1	Downward force due to slope F_2	$\frac{s_1}{s_2}$	$\frac{F_2}{F_1}$
	10 cm			
	20 cm			
	30 cm			
	10 cm			
	20 cm			
	30 cm			

Evaluation:

9. Calculate the ratio of the height s_1 to the length s_2 of the inclined plane in each case.
   Enter the results ▶ Table.
10. Calculate the ratio of the downward force due to slope F_1 to the force due to weight F_2 in each case.
    Enter the results ▶ Table.
11. Compare the ratios $\frac{s_1}{s_2}$ und $\frac{F_2}{F_1}$.

___

___

12. Formulate an equation describing the downward force due to slope .

___

13. What statement can you make, based on the equation for F_2?

___

___

Work on an inclined plane

Assignment: To investigate the "Golden Rule of Mechanics" on an inclined plane.

Apparatus:
2 stand bases
1 stand rod, 25 cm
1 stand rod, 50 cm
1 sleeve block
1 knockout spindle
1 inclined plane
1 dynamometer, 1.5 N
2 pulleys, 50 mm ⌀
1 coupler plug
2 weights
1 tape measure
1 universal marker pen

Setup:

1. Set up the apparatus as shown in fig. 1.

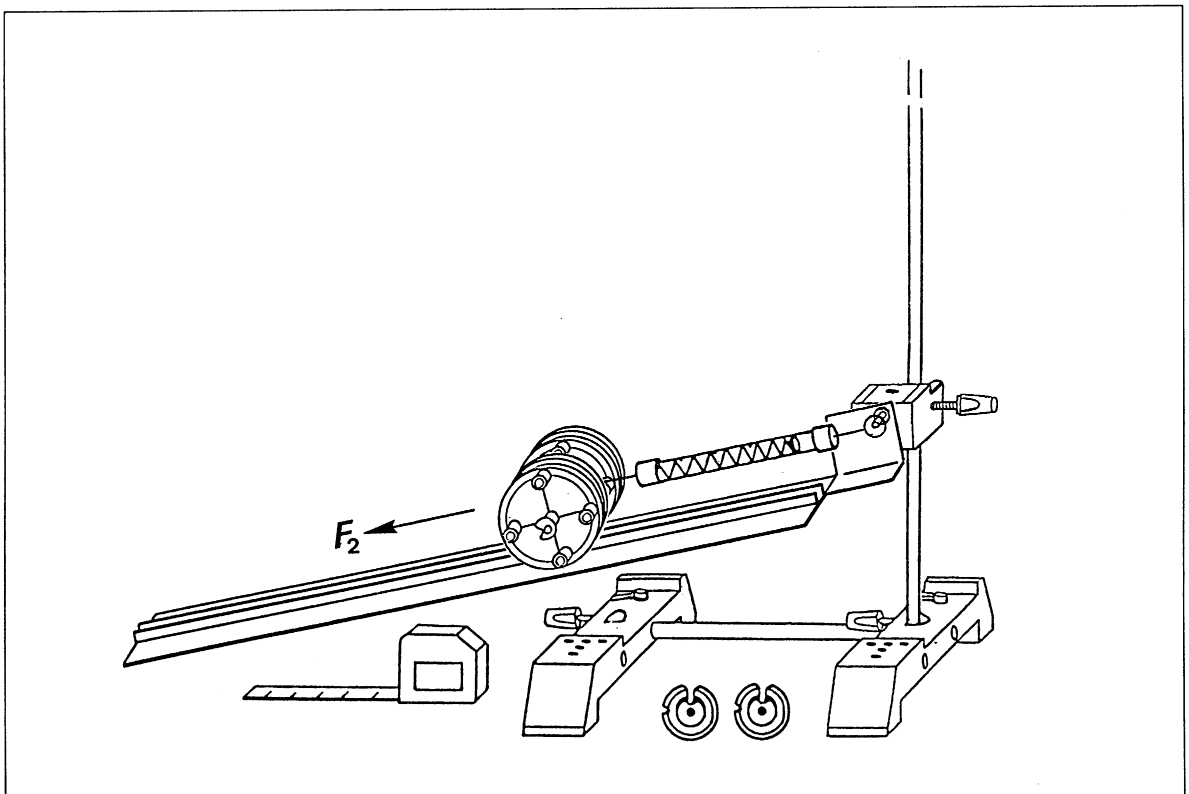


Fig. 1 Inclined plane: Measuring the tractive force F_2

2. Insert the spindle into a hole in the sleeve block and suspend the inclined plane from it.
3. Fasten the two pulleys together using the connector plug. ▶ Fig. 2

   You only attach the weights at a later stage.

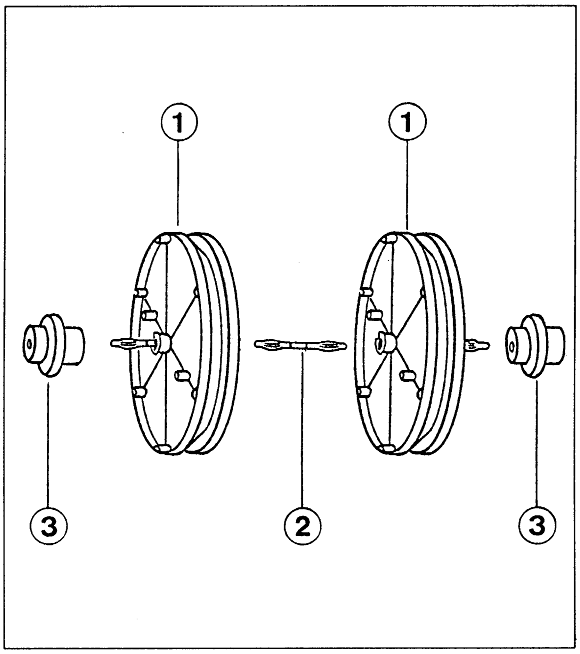


Fig. 2 Plugging together two pulleys **(1)** to form a "double pulley" using a coupler plug **(2)**. Increasing the weight by attaching weights **(3)**.

Performing the experiment:

4. Use the dynamometer to determine the force due to weight F_1 of the double pulley.
   Enter your readings ▶ Table
5. Attach the weights. What is F_1 now?
   Enter your readings ▶ Table.
6. Measure off a distance s_1 = 30 cm from the bottom of the inclined plane and make a mark in the appropriate place with the universal marker.
7. Set the height of the rail to s_1 = 10 cm, where s_2 = 30 cm.
8. Position the double pulley (with no weights attached) at the bottom of the rail. ▶ Point A in fig. 3.
9. What tractive force (pull) F_2 is required to move the double pulley from A to B?

   Hold the dynamometer so that it is parallel to the inclined plane!

   Note the value of F_2 ▶ Table.
10. Repeat the same experiment with weights attached.

    Determine the value of F_2.

    Enter your readings ▶ Table.

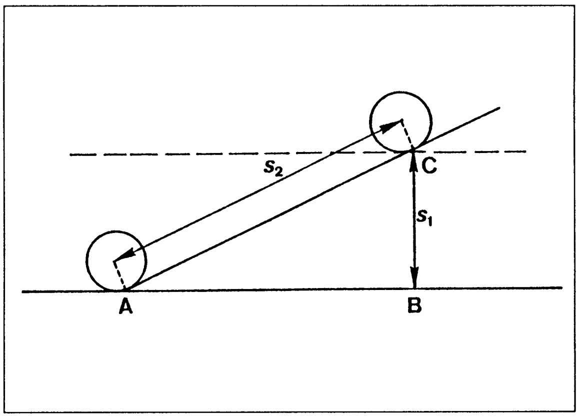


Fig. 3 Distances describing the inclined plane
s_1 : height
s_2 : length

11. Set the height of the rail to s_1 = 20 cm where s_2 = 30 cm, and repeat steps 8 to 10.
Table

	s_2 = 20 cm				
Load	s_1	F_1	F_2	W_1	W_2
Pulleys	10 cm				
Pulleys + weights	10 cm				
Pulleys	20 cm				
Pulleys + weights	20 cm				

Evaluation:

12. Calculate the lifting work $W_1 = F_1 \cdot s_1$.
Enter the result ▶ Table.
13. Calculate the pulling work $W_2 = F_2 \cdot s_2$.
Enter the result ▶ Table.
14. What is the relationship between lifting work and pulling work?

____

15. What does the Golden Rule of Mechanics say?

____

____

____

____

____

____

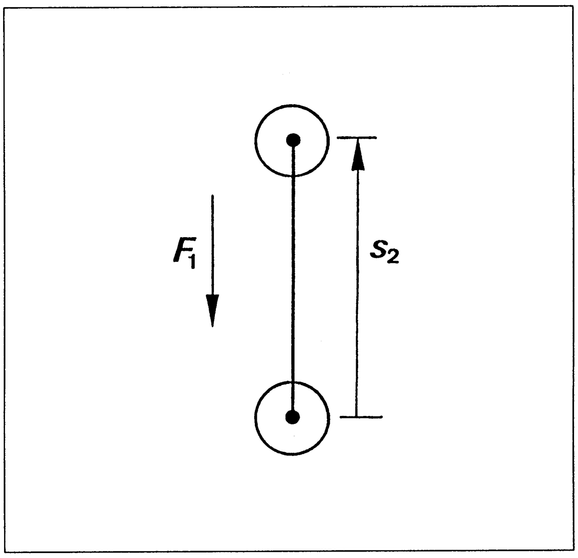


Fig. 4 Force due to weight F_1 and distance lifted s_1

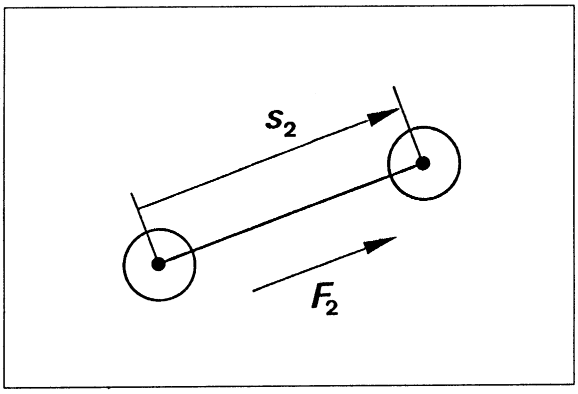


Fig. 5 Tractive force (pull) F_2 and distance s_2 along the inclined plane.

Energy conversion

Assignment: To determine the capacity for work (potential energy) of a moving body.

Apparatus:

2 stand bases
1 stand rod, 25 cm
1 stand rod, 50 cm
1 pointer
1 universal socket
1 tape measure, 1.5 m
1 universal marker pen

Student's Sheet 2

Setup:

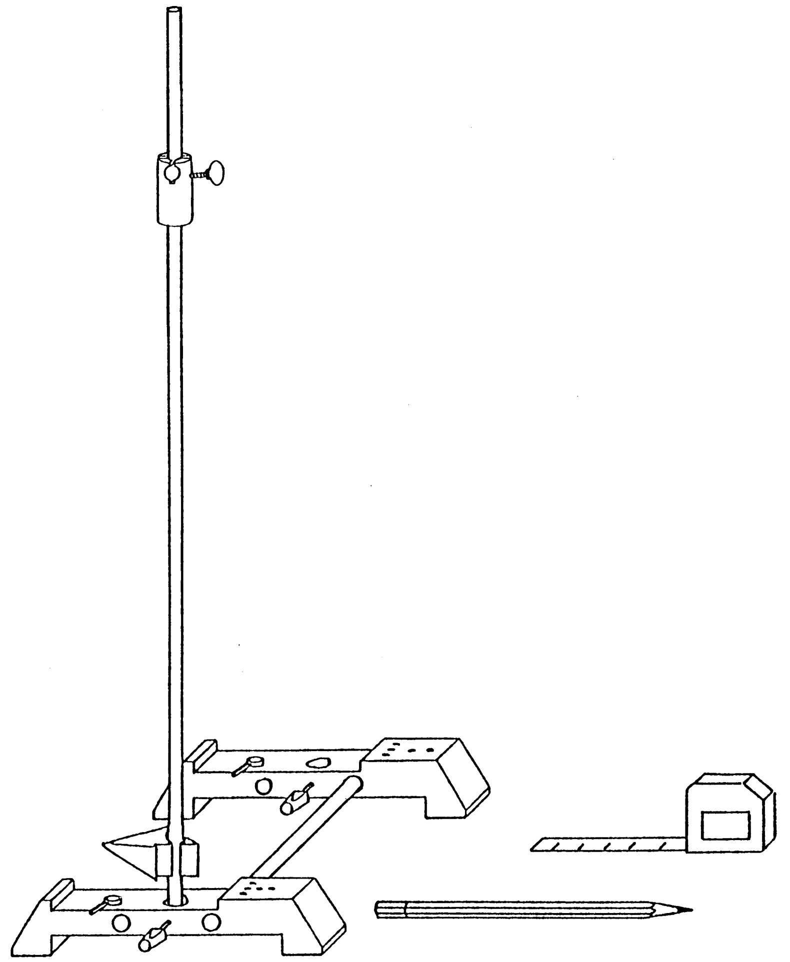


Fig. 1 Setup for energy conversion experiment

1. Assemble all the components of the stand as shown in fig. 1.

2. Clamp the stand rod vertically in the stand base so that as much of it protrudes from the base as possible – it should extend about 48 cm above the base.

Preparing the report:

3. Copy out table 1.

Student's Sheet 3

Performing the experiment:

4. Fasten the universal socket to the stand rod so that its top edge coincides with the very top of the stand rod.
5. Attach the pointer to the stand rod at a distance of 40 cm from the underside of the universal socket and mark a zero reference point on the stand rod at this height, using the universal marker pen.

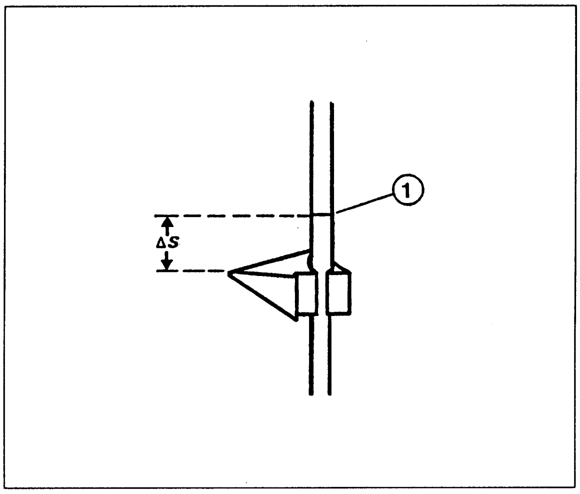


Fig. 2 Sketch for measurement of the distance Δs
(1) Zero reference point

6. Slide the universal socket down the rod until h = 10 cm above the pointer and fasten it in place again; check the height, then loosen the screw but keep hold of the socket. Finally, release it so that it falls down onto the pointer.
7. Measure the distance Δs by which the pointer was displaced (due to the impact of the socket) (fig. 2) and note it down in table 1.
8. Move the pointer back up to the zero reference point and repeat steps 6 – 8 for various heights h.

Observations and measurements:

9. Table 1

Height of fall h	Distance of displacement Δs
10 cm	
20 cm	
30 cm	
40 cm	

Evaluation:

10. The greater the height of the fall, the _______ the distance by which the pointer is displaced, hence work accomplished.

List of apparatus

Maximum quantity	Description	Cat. No.	Apparatus required in experiment (no. of items / lengths in cm)														Number supplied in STM apparatus set	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	BMC 1	MEC 1
2	Stand base	301 21			2	2	2		2	2	2	2	2	2	2	2	2	
1	Stand rod, 25 cm	301 26			1	1	1		1	1	1	1	1		1	1	1	
2	Stand rod, 50 cm	301 27			1	2	1	1	2	2	2	2	1	2	1		2	
2	Sleeve block	301 25			1		1	1		2	2	2	1	1	1		2	
	Double socket	301 09															1	
1	Universal socket	666 615							1							1	1	
	Universal clamp	666 555															1	
1	Pair of pointers	301 29							1						1		1	
1	Universal marker	309 45											1				1	
1	Cord	200 70 322	1	1	1				1		1	1	1				1	
2	Retaining clips	314 04			2					2		2	1		1		3	
1	Tape measure	311 78				1	1		1				1				1	
	Double scale	340 82															1	
1	Set of weights, 6 pcs	340 85	1	1	1		1		1	1	1	1	1		1		1 (6)	
1	Aluminium cuboid	362 32	1	1		1											1	
1	Metal plate	200 65 559							1							1	1	
	Vernier caliper	311 52																1
1	Dynamometer, 1.5 N	314 01	1	1			1			1	1	1						1
1	Dynamometer, 3 N	314 02				1	1	1		1		1						1
1	Knockout spindle, 5.5 cm	340 811			1		1	1						1				1
1	Lever with pointer	340 831								1				1				1
	Balance pan with stirrup	342 47																
	Set of weights	590 27																1
	Load hook	340 87																1
	Coupler plug	340 89			1													1
1	Rubber rings	340 90						1										1
1	Pulley, 5 cm	340 911									1							2
1	Pulley, 10 cm	340 921			1						1							2
2	Pulley bridge	340 930	2	2	1													
	Inclined plane	341 221																1
1	Leaf spring	352 051					1	1	1							1		1
1	Helical spring, 1.5 cm ⌀	352 07													1			1
1	Helical spring, 2 cm ⌀	352 08													1			1
	Manometric capsule for hydrostatics	362 301																1
	Capillary device	362 36																1
	Lead shot	362 351																1
	Plastic pipe, 25 mm ⌀	665 240																1
	Stopper without a hole	667 257																1
1	Stopwatch e.g.	313 07											1	1	1	1		
1	Pair of scissors e.g.	310 08	1	1							1	1	1					

List of apparatus – cont.

Maximum quantity	Description	Cat.-No.	Apparatus required in experiment														Number supplied in apparatus sets	
			15	16	17	18	19	20	21	22	23	24	25	26	27	28	BMC 1	MEC 1
2	Stand base	301 21	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
1	Stand rod, 25 cm	301 26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
2	Stand rod, 50 cm	301 27	1	1	1	1	1		1	2	1	2	1	1	1	1	2	
–	Sleeve block	301 25	2	2	2	1	1		1	2	2	2	1	1	1		2	
–	Double socket	301 09															1	
1	Universal socket	666 615										1				1	1	
	Universal clamp	666 555															1	
1	Pair of pointers	301 29						1	1			1				1	1	
1	Universal marker	309 45														1	1	
1	Cord	200 70 322					1		1	1	1	1	1				1 (20 m)	
2	Retaining clips	314 04	2	2	2					2	2	2	2				3	
1	Tape measure	311 78								1		1	1	1	1	1	1	
1	Double scale	340 82	1	1	1												1	
1	Set of weights, 6 pieces	340 85	1	1		1	1		1	1	1	1	1	2	2		1 (6 pieces)	
–	Aluminium cuboid	362 32															1	
–	Metal plate	200 65 559															1	
	Vernier caliper	311 52																1
1	Dynamometer, 1.5 N	314 01	1	1		1	1		1	1		1	1	1	1			1
1	Dynamometer, 3 N	314 02	1	1		1					1							1
1	Knockout spindle, 5.5 cm	340 811	1	1	1	1	1	1				1		1	1			1
1	Lever with pointer	340 831	1	1	1	1												1
2	Balance pan with stirrup	342 47			2													2
1	Set of weights	590 27			1													1
1	Load hook	340 87								1	1	1	1					1
1	Coupler plug	340 89					1	1				1	1	1	1			1
1	Rubber rings	340 90						1										1
2	Pulley, 5 cm	340 911					1	1	1	1	2	2	2	2	2			2
2	Pulley, 10 cm	340 921					1	1				2	2					2
2	Pulley bridge	340 930										2	1					2
1	Inclined plane	341 221												1	1			1
–	Leaf spring	352 051																1
–	Helical spring, 1.5 cm ∅	352 07																1
–	Helical spring, 2 cm ∅	352 08																1
–	Manometric capsule for hydrostatics	362 301																1
–	Capillary device	362 36																1
–	Lead shot	362 351																1 (100 g)
–	Plastic pipe, 25 cm ∅	665 240																1
–	Stopper without a hole	667 257																1
1	Pair of scissors	667 017					1		1	1	1	1	1					