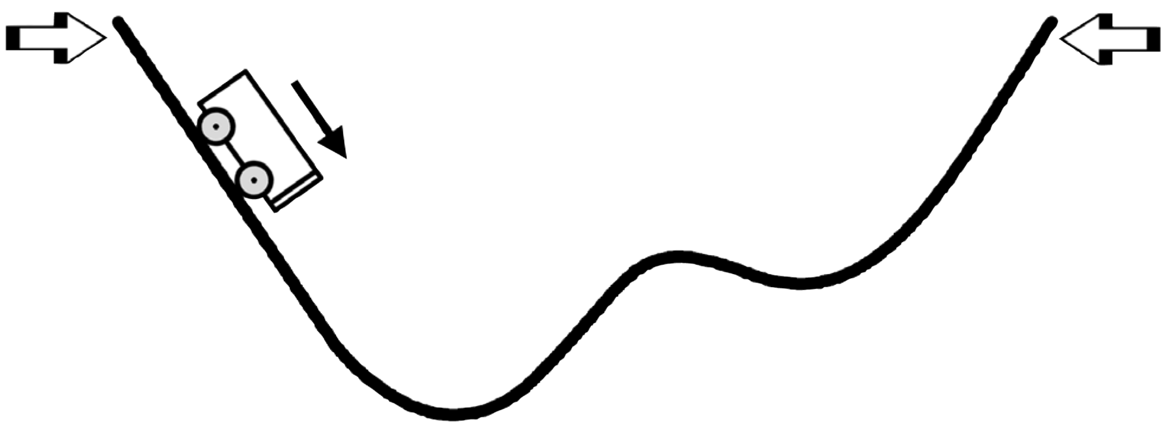
Demonstration experiments

Demo advanced

Mechanics on the Magnetic Board



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Demo advanced
Demonstration experiments
Mechanics on the Magnetic Board

Order No. 01153-02

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Demo advanced Demonstration experiments Mechanics on the Magnetic Board
Order No. 01153-02

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1st edition

Contents

Energy conversion in a switchback

The switchback is to be used to demonstrate that mechanical forms of energy can be converted into one another.

Materials

Demo-Board Physics	02150.00	1
Rule for demo-board	02153.00	1
Switchback for Demo-board, magnetic	02159.00	1
Water soluble pen for overheads		

Set-up and Procedure

— Use the pen and the rule to draw a line on the demo-board parallel to the upper edge (distance from it, e.g., about 10 cm).
— Fit the switchback on the demo-board and first adjust it to an almost symmetrical form, take care in doing this that both ends of it lie on the drawn line, and so are at the same height.
— Place the car standardly supplied with it on the switchback (Fig. 1) and let go of the car.
— Observe the movement of the car.
— Repeat the procedure.
— Describe your observations (1).
— Change the shape of the track, but ensure that the ends of it are always at the same height (see Fig. 2).
— Observe the movement and describe what you observe (2).

Results

(1) The car moves downwards and accelerates to the lowest point of the track, then decelerates while moving upwards to a point which is lower than the starting point.
Now the same movement occurs in the reverse direction, and this whole procedure is repeated until the car comes to rest at the lowest point of the track.
(2) In principle, the movement of the car after letting go of it is the same. It rolls down and up with decreasing height of the point of reversal. When the track has 2 minimums, as shown in Fig. 2, the car finally comes to rest in the one or the other of these.

Fig. 2

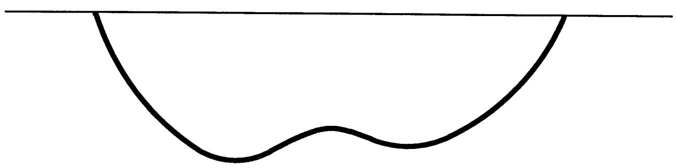
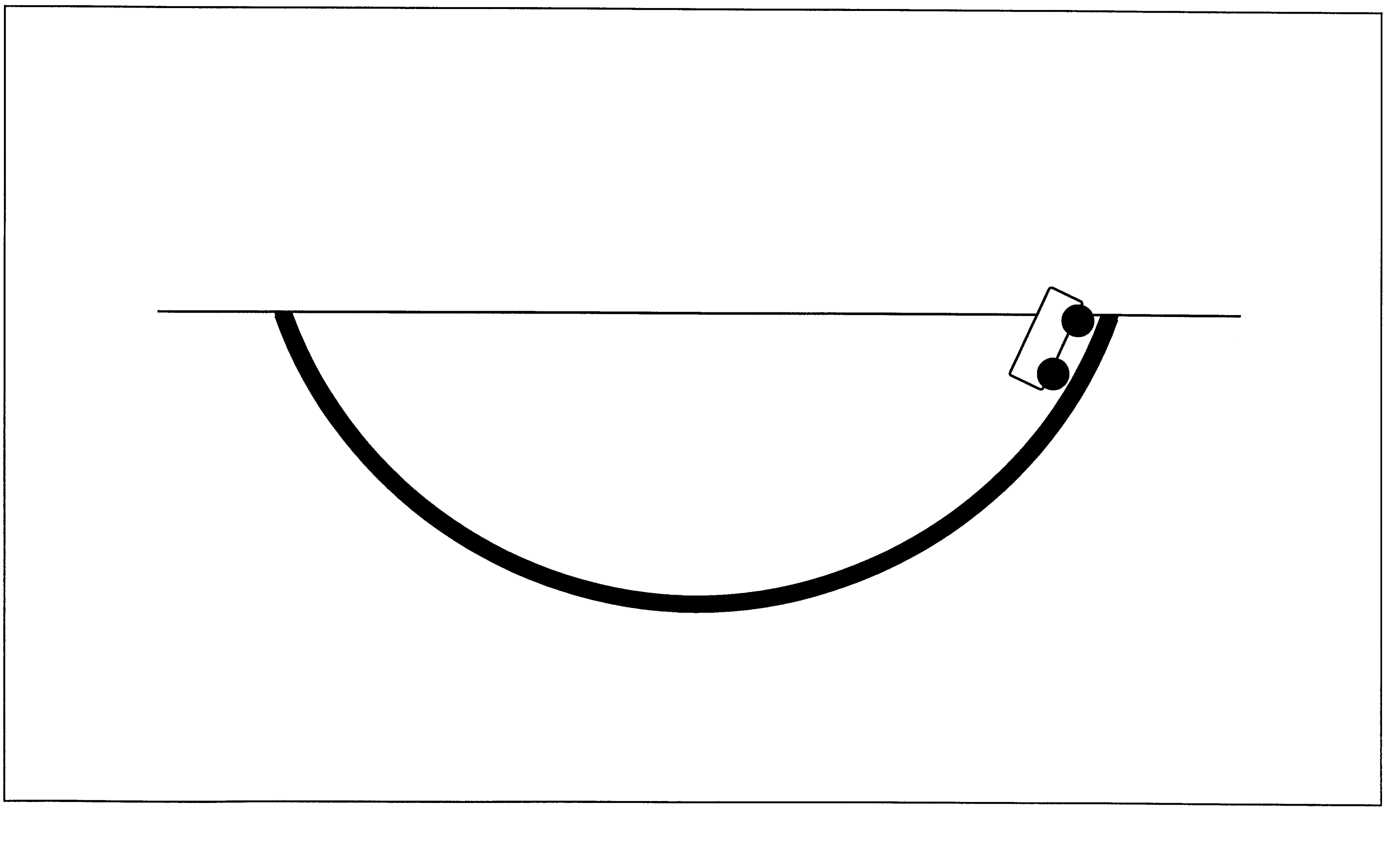


Fig. 1



Evaluation

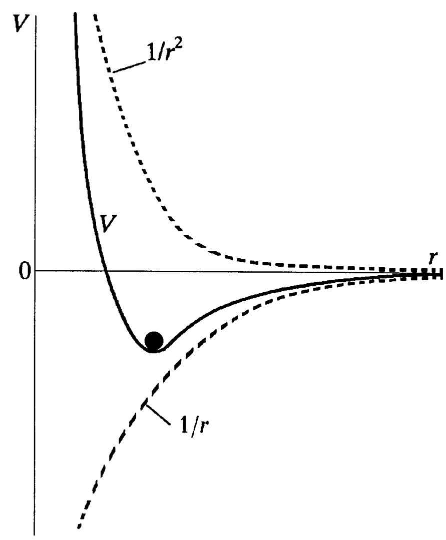
The potential energy W_{pot} which the car possesses at the start of its movement, is converted into kinetic energy W_{kin} until the lowest part of the track is reached and W_{kin} is at its maximum.
Now W_{kin} is converted back into W_{pot} but this does not again reach the initial value, because part of the energy has been converted into heat (thermal energy) by frictional work.
In end effect, friction is the cause of the car coming to rest at the lowest part of the track after a number of conversion processes W_{pot} <–> W_{kin} have occurred.

Notes

We recommend that, before the car is released, you ask the students to make predictions on which movement will result. This contributes both to motivation and to careful observation.
The following question could be interesting, for example: Assuming the track is symmetrical, should the flanks of it be more steeply or less steeply curved for the most possible conversion processes to occur?
Answer: They must be steeply curved. Reason: 1. W_{pot} is then as large as possible. 2. The frictional force is then particularly low over long stretches of the track because $F_R = \mu \cdot F_N = \mu \cdot F_G \cdot \cos\alpha$. With steep flanks, therefore, relatively much potential energy is available, from which only a relatively small amount is converted into heat during each completed movement.
The correct answer can be confirmed experimentally. When the flanks are steep, 6 to 8 back and forth movements can be observed, with a very flat track only 2, for example.

The switchback could also be used in Atomic Physics or in Chemistry to replicate the potential for an electron circulating around an atomic nucleus. A wooden ball (d = 25 mm, order no. 02470.00) would come to rest at the energetically most favourable point of the curve (see Fig. 3).

Fig. 3: The potential energy of an electron in a hydrogen atom consists of two parts:
Coulomb energy, proportional to $-1/r$, and energy of the orbital movement of the electron around the nucleus, proportional to $+1/r^2$



A helical spring is to be used to work out the tensile energy for a distorted elastic body.
Two experimental variations are described.

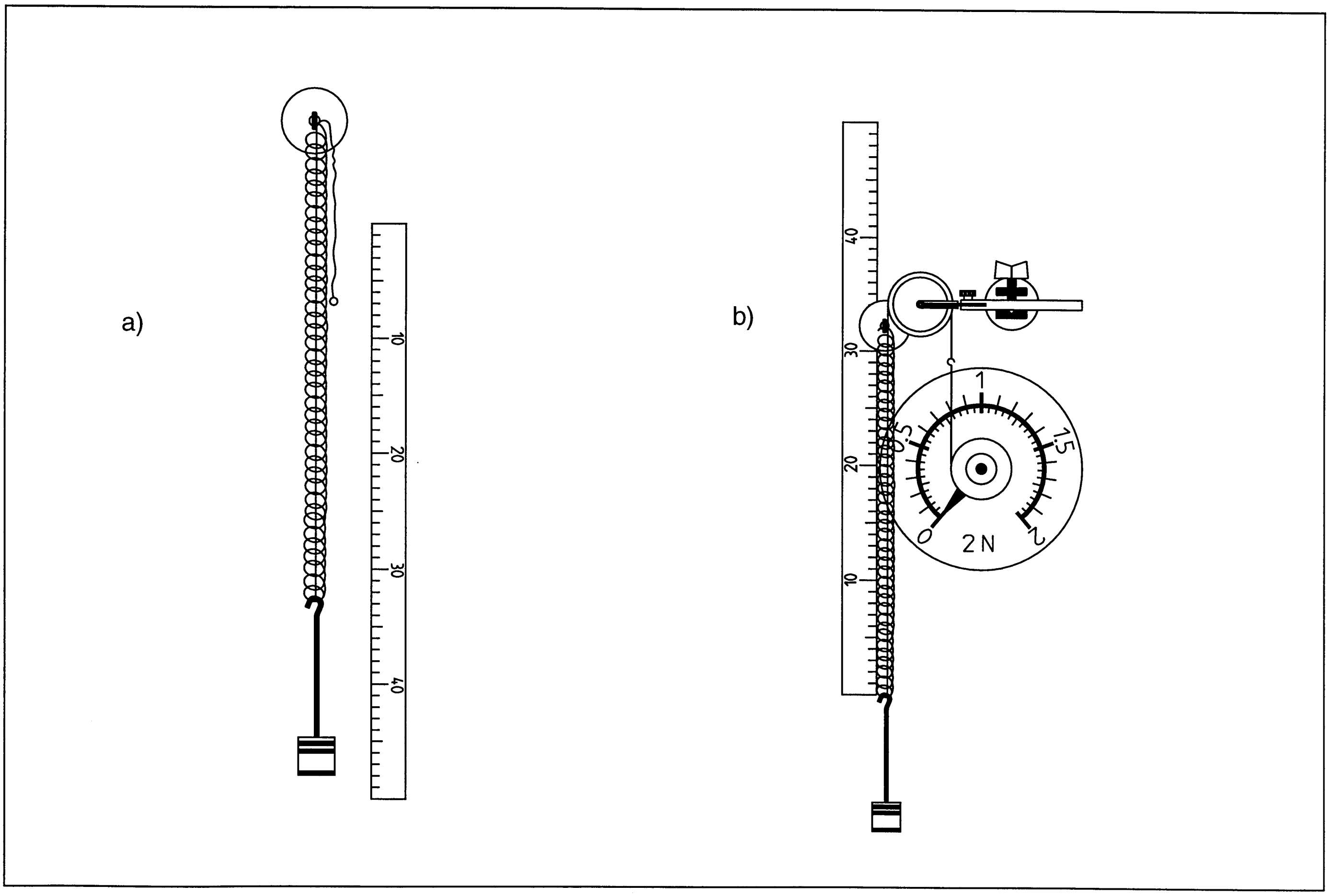
Materials

Demo-Board Physics	02150.00	1
Clamp with magnetic base	02151.01	1
Hook with magnetic base	02151.03	1
Rule for demo-board	02153.00	1
Pointer for demo-board, 4 pcs	02154.01	1
Shelf, magnetically held	02155.00	1
Torsion dynamometer	03069.03	1
Helical spring, 3 N/m	02220.00	1
Weight holder f. slotted weights	02204.00	1
Slotted weight, 10 g, black	02205.01	1
Slotted weight, 10 g, silver bronze	02205.02	1
Slotted weight, 50 g, silver bronze	02206.02	1
Pulley, movable, dia. 65 mm, w. hook	02262.00	1
Rod for pulley	02263.00	1
Fish line, 1 m from	02090.00	1
Water soluble pen for overheads		

Set-up and Procedure 1

— Fit the hook with magnetic base an the upper edge of the demo-board and hang the helical spring on it.
— Position the rule so that the zero mark is exactly behind the lower end of the spring (Fig. 1a).
— Thread an approximately 65 cm length of fishing line, which has loops tied at each end, through the spring.
— Hang the holder for weights, loaded with a 10 g slotted weight, on the end of the spring and in the fishing line loop. Read the increase in length s of the spring from the rule and enter this value in Table 1.
— Increase the load on the holder for weights in steps of 20 g, measuring and recording the new length at each step.
— Fix the pulley with rod in the clamp, also positioning it at the edge of the board, so that the outer side of the pulley is near to the hook.
— Fit on the torsion dynamometer, lead the fishing line over the pulley and hang the dynamometer hook in the free loop of the line.
— Set the dynamometer to zero (Fig. 1b).

Fig. 1



- Turn the rule through 180° and re-position it, so that the zero mark is again exactly behind the lower end of the spring, which is now under tension.
- Lower the dynamometer until a tensile force of 0.2 N is displayed (measuring range 2 N).
- Read off from the scale the distance *h* which the loaded weight holder (*m* = 100 g) is lifted. Enter this value in Table 2.
- Move the dynamometer stepwise to readings of 0.4 N, 0.6 N and 0.8 N, read the height *h* which results at each step and note it.
- Finally, determine the force which is necessary for the spring to return completely to its normal rest position; enter the values measured for this force and for *h* in Table 2.

Results 1

Table 1 Table 2

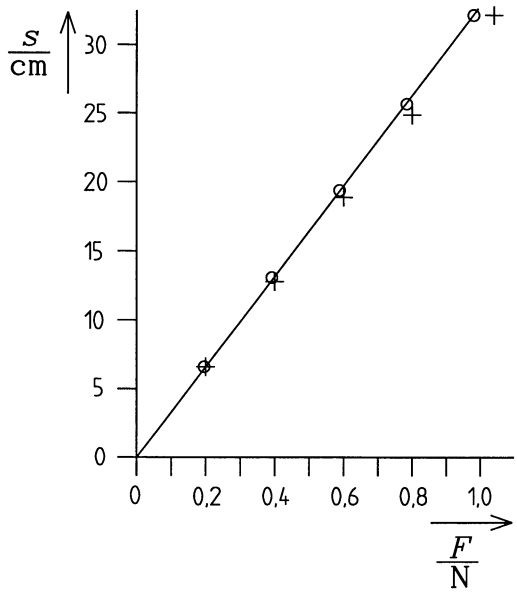
m/g	F_G/N	s/cm
20	0.196	6.6
40	0.392	13.1
60	0.588	19.4
80	0.784	25.7
100	0.980	32.2

F/N	h/cm
0.2	6.6
0.4	12.8
0.6	18.9
0.8	24.9
1.04	32.2

Evaluation 1

The graph of the measured values from Table 1 (mark each point with an o) gives a staight line which passes through the origin (Fig. 2). This was to be expected because of the validity of Hooke's Law $F = D \cdot s$. The force F_{sp} required for the tensile work is not constant, but increases proportionally with the displacement *s* of the spring. For this reason, the tensile work **cannot** be calculated with the formula $W = F \cdot s$.

Fig. 2



Now plot the measured values from Table 2 in the coordinate system in Fig. 2 (use + to mark them). Within the measurement accuracy, these points also lie on a straight line.

This means: The work W_K is performed on moving the dynamometer to restore the spring to equilibrium. This work is just as large as the work Wsp required for the maximum displacement of the spring. When the tension is relaxed, however, by virtue of the work W_{sp} and the work W_K together, the displacement work $W_H = F_G \cdot h$ has been performed, whereby $h = s$ and F_G, the maximum force working on the spring during the tensile work.

We therefore have:

$$W_H = W_K + W_{sp} = 2W_{sp} \text{ and herewith}$$

$$W_{sp} = \frac{1}{2} W_H = \frac{1}{2} F_G \cdot h$$

Generalizing this, we have, with $F_G = F$ and $h = s$, and also by virtue of $F = D \cdot s$ (Hooke's Law):

$$W_{sp} = \frac{1}{2} F \cdot s = \frac{1}{2} D \cdot s^2 .$$

From which we can derive the sought-for formula for the tensile energy :

$$E_{sp} = \frac{1}{2} F \cdot s .$$

Set-up and Procedure 2

- Fit the hook with magnetic base an the upper edge of the demo-board and hang the helical spring on it.
- Load the holder for weights with three 10 g slotted weights and hang it on the helical spring.
- Mark the bottom edge of the holder for weights with a blue pointer.
- Lift the holder for weights up until the spring is just relaxed, hold it there and again mark the position of the bottom edge, this time with a red pointer (Fig. 3).
- Let go of the holder for weights and mark the lowest point which the bottom edge reaches with the second red pointer.
- Stop the vibration and position the shelf at the height of the second red pointer.
- Lift the holder for weights up again as previously, let it go and check if the holder lightly touches the shelf.
- Should it not touch the shelf, repeat this procedure after an appropriate change in the position of the shelf, until the correct position is reached. Correct the position of the lower red pointer accordingly.
  (Note on how to find this position more quickly: The red pointers should be at an equal distance from the blue pointer).

— Remove the holder for weights. Use the pen to draw in appropriate markings for the evaluation of the experiment on the demo-board (Fig. 4).
— Use the rule to determine the distances of the pointers from each other.

Results 2
See Fig. 4
$s \;= 26$ cm
$s_1 \;= s_2 = 13$ cm

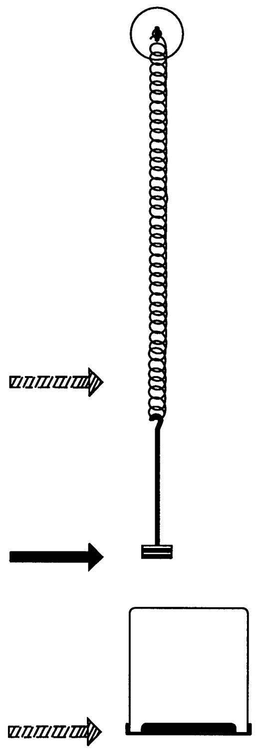
Evaluation 2
The distance s is double the distance s_1.
After being let go of, the body (the loaded holder for weights) falls the distance s. In doing this, the potential energy $E_{pot} = F_G \cdot s$ is converted into tensile energy E_{sp} of the spring, and this again into potential energy of the vibrating system etc..
The following is valid for the lower reversal point:

$$E_{sp} = E_{pot} = F_G \cdot s\,.$$

To reach this point as resting-point, the force acting must be $F = 2 \cdot F_G$. In general, therefore:

$$E_{sp} = \frac{1}{2} F \cdot s\,.$$

Fig. 3



and, with $F = D \cdot s$ (Hooke's Law)

$$E_{sp} = \frac{1}{2} D \cdot s^2\,.$$

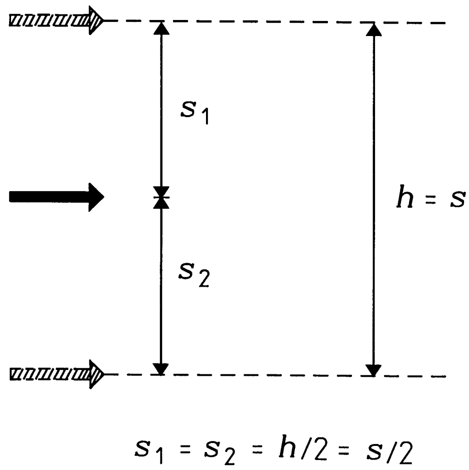
Notes
The values measured for the force with which the dynamometer pulls on the line in the second part of Experiment 1, have a larger tolerance than the values measured during the stretching of the spring in the first part. For this reason, the measured values denoted by + do not normally lie exactly on the straight line in Fig. 2, which represents the characteristic line for the spring.
The second experiment is offered as a variation for working out the formula for tensile energy. We have here refrained from working out the characteristic line for the spring, so that this experiment takes less time than Experiment 1.
For the calculation of mechanical work, we have in general

$$W = \int_{s_1}^{s_2} F(s)\, ds$$

and for the present case:

$$W = \int_{0}^{s} F(s)\, ds$$

Fig. 4



In the case that F = constant, $W = F \cdot s$ and W means geometrically the area of a rectangle which is formed in an F-s coordinate system by the coordinates for F and s. In the case that $F \sim s$, W means the area of a right-angled triangle whose legs are the coordinates for F and s. This can be discussed during the evaluation of Experiment 1, should the students have sufficient background knowledge.

U-tube manometer

The aim of this experiment is to show that a U-tube that is partially filled with a liquid can be used as a pressure measuring device (manometer).

Equipment

1	Clamp on a magnetic base	02151-01
1	Scale for the demonstration board	02153-00
1	Gas syringe holder on a magnetic base	02156-00
1	Support rod, stainless steel, *l* = 100 mm, *d* = 10 mm	02030-00
2	Slotted weight, black, 10 g	02205-01
2	Slotted weight, silver bronze, 10 g	02205-02
1	Slotted weight, black, 50 g	02206-01
1	Gas syringe, 50 ml	02610-00
1	Rubber caps, 1 taken from	02615-03
2	Glass tube holder with a tape measure clamp	05961-00
1	Beaker, 100 ml, plastic	36011-00
1	Glass tubes, *d* = 8 mm, *l* = 375 mm, 2 taken from	36701-67
1	Funnel, d= 50 mm, plastic	36890-00
1	Silicone tube, *d*i = 6 mm, 0.6 m	47530-00
1	Laboratory marker, non-permanent, black	46402-01

Additional equipment

1	Demo physics board with a stand	02150-00
1	Microspoon, stainless steel	33393-00
1	Food colouring, patent blue V	48376-04

Set-up

- Set the U-tube manometer up as shown in Figure 1.
- Connect the two glass tubes with a piece of silicone tube of approximately 10 cm and join them by way of the glass tube holders in order to form a firm U-tube.

Fig. 1: Experiment set-up (at the beginning of the experiment, the gas syringe is used <u>without</u> the plunger)

- Clamp the support rod horizontally into the upper glass tube holder and fasten it into the clamp.
- Place the scale between the glass tubes on the board so that the 20 cm mark (as the "zero" of the manometer) is located approximately in the middle between the two glass tube holders.
- Colour some water in the 100 ml beaker. This requires only a small amount (tip of a spatula) of food colouring.
- Fill the manometer carefully with the coloured water approximately up to the 20 cm mark (use the funnel with a small piece of tube).
- Move the scale of the U-tube manometer so that the water column ends around a height of 20 cm. The lower edge of these menisci can be marked on the glass tubes by way of a laboratory marker, if desired.
- Remove any trapped air bubbles by squeezing the tube.
- Position the 50 ml gas syringe <u>without its plunger</u> on the board by way of the holder.
- Connect the gas syringe to the manometer with a piece of tube of approximately 50 cm.

Procedure

- Insert the plunger carefully into the cylinder of the gas syringe and read the difference in height h between the menisci of the water columns as quickly as possible off the U-tube. Note the values of h down in Table 1.
  Note: If the 20 cm mark has been adjusted as the zero line, it is sufficient to read the height difference off on only one side and to double this value.
- Pull the out of the syringe, load with a slotted weight of 10 g, and reinsert it into the cylinder. Note down h.
- Repeat this loading process in steps of 10 g, each time measuring and noting down the values for h.

Observations and results

Cross-sectional area of the cylinder A = 4.9 cm^2

Mass of the plunger m = 67 g

See Table 1 for the measurement values for the mass and height difference as well as for additional calculations.

Evaluation

Calculate the weight force with which the plunger presses on the air in the cylinder based on the given mass values and enter the force values into column 3 of Table 1.

$$F_g = m \cdot g \cdot h$$

With g = 9.81 m/s^2.

Table 1

m /g	h /cm	F_G /N	$\frac{p}{\text{N/cm}^2}$	$\frac{h/p}{\text{cm}^3/\text{N}}$
67	13.4	0.66	0.135	99
77	15.0	0.75	0.153	98
87	16.8	0.85	0.173	97
97	19.6	0.95	0.194	101
107	21.8	1.05	0.214	101
117	23.9	1.15	0.235	101

Calculate the gas pressure values based on the weight force and cross-sectional area of the cylinder. Enter the values into column 4.

$$p = F_g / A$$

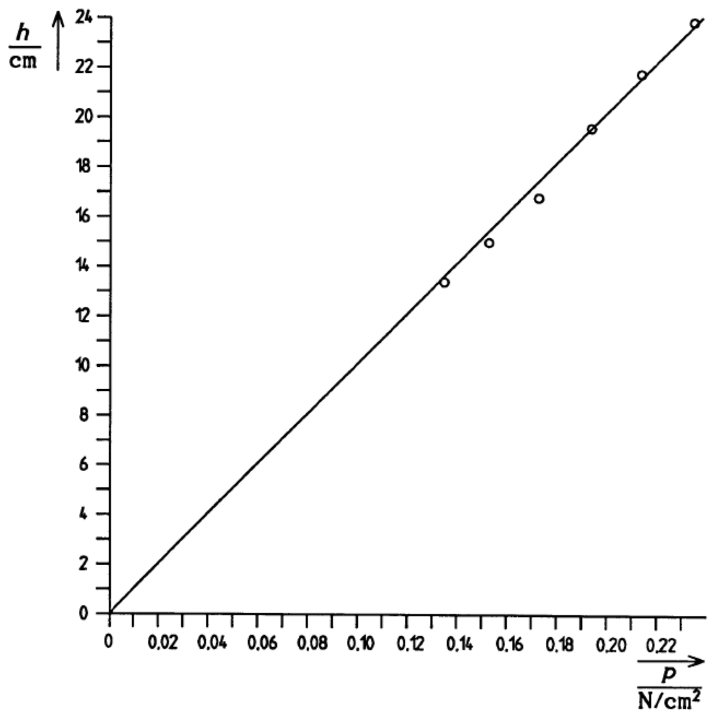
When the values for the height difference *h* are plotted against the pressure *p* (Fig. 2), the resulting graph is a good approximation to a straight line. The extension of this line runs through the origin of the system of coordinates. This means that *h* is proportional to *p*:

$$h \sim p$$

This can be confirmed by calculating the quotients (see column 5 in Table 1).

This means that the U-tube can be used as an instrument for measuring the pressure in gases. For this purpose, the manometer is connected to the vessel that contains the gas.

Fig. 2



Notes

- Prior to the introduction of the SI units, cm WC (centimetre of water column) was the pressure unit that was used when relatively small pressure or pressure differences were measured.
- For the quality of the values that are measured for the height h, it is very important that the plunger of the gas syringe does not get stuck or seal the gas syringe in an insufficient manner. Contaminants should be removed by careful cleaning with alcohol or acetone.
- After the experiment, attach a rubber cap to the connector of the gas syringe in order to prevent the plunger from falling out of the syringe.

Room for notes

The hydrostatic pressure (pressure exerted by weight) depends on the depth of immersion *h* and on the density ρ of a liquid. This experiment demonstrates the relationship between the pressure *p* and the quantities *h* and ρ.

Equipment

1	Clamp on a magnetic base	02151-01
1	Clamp holder, *d* = 0…13 mm, on a magnetic base	02151-07
2	Scale for the demonstration board	02153-00
1	Pointers for the demonstration board, 4 pieces	02154-01
1	Support plate, magnetic	02155-00
1	Support rod, stainless steel, *l* = 100 mm, *d* = 10 mm	02030-00
2	Glass tube holder with a tape measure clamp	05961-00
1	Beaker, 600 ml, tall	36006-00
1	Beaker, 100 ml, plastic	36011-00
1	Funnel, d= 50 mm, plastic	36890-00
1	Glass tubes, *d* = 8 mm, *l* = 375 mm, 2 taken from	36701-67
1	Silicone tube, *d*i = 6 mm, 0.6 m	47530-00
1	Laboratory marker, non-permanent, black	46402-01

Additional equipment

1	Demo physics board with a stand	02150-00
1	Microspoon, stainless steel	33393-00
1	Food colouring, patent blue V	48376-04
1	Glycerol, 250 ml	30084-25
1	Alcohol (spirit) (250 ml taken from 31150-70)	31150-70
1	Ruler, 20 cm, transparent	

Set-up

- Set the U-tube manometer up as shown in Figure 1.
- Connect the two glass tubes with a piece of silicone tube of approximately 10 cm and join them by way of the glass tube holders in order to form a firm U-tube.

Fig. 1: Experiment set-up (at the beginning of the experiment, the probe is located above the beaker)

- Clamp the support rod horizontally into the upper glass tube holder and fasten it into the clamp so that it can be seen from the front (Fig. 1). As a result, the glass tubes are very close to the board.
- Place the scale between the glass tubes on the board so that the 20 cm mark (as the "zero" of the manometer) is located approximately in the middle between the two glass tube holders.
- Colour some water in the 100 ml beaker. This requires only a small amount (tip of a spatula) of food colouring.
- Fill the manometer carefully with the coloured water approximately up to the 20 cm mark (use the funnel with a small piece of tube).
- Move the scale of the U-tube manometer so that the water column ends around a height of 20 cm. The lower edge of these menisci can be marked on the glass tubes by way of a laboratory marker, if desired.
- Remove any trapped air bubbles by squeezing the tube.
- Fasten the magnetic support plate next to the manometer in the lower area of the board as shown in Fig. 1.
- Position the clamp holder with the immersion probe above the support plate and clamp in the immersion probe.
- Connect the immersion probe to the U-tube manometer with a piece of tube of approximately 50 cm.

Procedure

- Fill the beaker with approximately 500 ml of water and place it on the support plate.
- Attach the second scale perpendicularly to the board next to the beaker so that the zero line is aligned with the water surface and that the water depth can be measured (Fig. 1).
- Lower the clamp holder with the immersion probe until the lower edge of the immersion probe is 2 cm below the water surface. Loosen the clamp of the clamp holder for the fine adjustment.

Note:
The depth of immersion h is the distance between the lower edge of the menisci of the water in the beaker and of the water at the lower edge of the immersion probe. Use a transparent ruler in order to ensure an exact measurement.

- Measure the height difference h_M at the manometer (between the lower edges of the menisci).
- Enter the measurement values h and h_M into Table 1.
- Lower the immersion probe further in steps of 2 cm, each time measuring h and h_M.
- In order to examine the dependence of the hydrostatic pressure on the density of a liquid, repeat the experiment with alcohol (spirit) and then with glycerol.

Observations and results

The deeper the immersion probe is immersed in the liquid, the greater the height difference will be in the manometer.

The height difference h_M at the manometer in the case of alcohol (spirit) is smaller than in the case of water for every immersion depth h. In the case of glycerol, it is greater.

All the measurement values have been entered into Table 1.

Evaluation

The values for h_M are plotted as a function of h for water, alcohol (spirit), and glycerol in the same system of coordinates (Fig. 2). This results in three straight lines. All of them pass through the origin, but they all have different gradients: Glycerol has the biggest gradient and alcohol (spirit) has the smallest.

Results

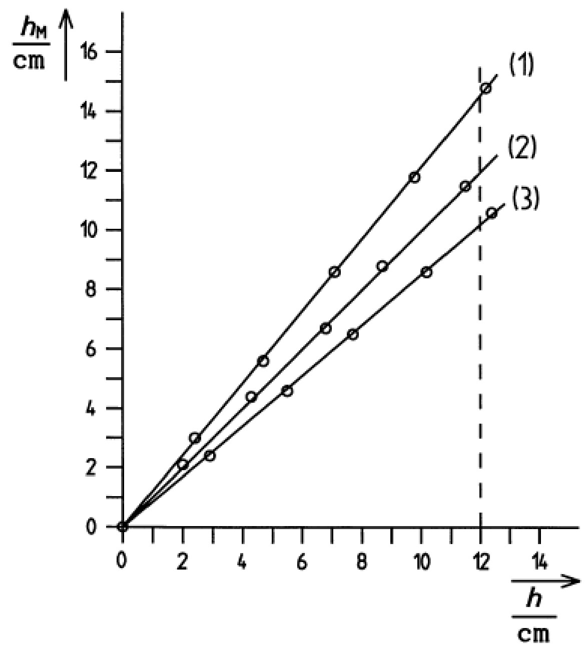
Table 1

Water		
h/cm	h_M/cm	h_M/h
2.0	2.1	1.05
4.3	4.4	1.02
6.8	6.7	0.99
8.7	8.8	1.01
11.5	11.5	1.00

Alcohol		
h/cm	h_M/cm	h_M/h
2.9	2.4	0.83
5.5	4.6	0.84
7.7	6.5	0.84
10.2	8.6	0.84
12.4	10.6	0.85

Glycerol		
h/cm	h_M/cm	h_M/cm
2.4	3.0	1.25
4.7	5.6	1.19
7.1	8.6	1.21
9.8	11.8	1.20
12.2	14.8	1.21

Fig. 2: (1) Glycerol, (2) water, (3) alcohol



The following applies to all of the liquids:

$h_M \sim h$ or h_M / h = const.

This is also substantiated by the calculation of the quotients (column 3 in Table 1).

The U-tube manometer is a pressure measuring instrument. The height difference h_M is a measure of the hydrostatic pressure p. The experiment, therefore, shows:

$p \sim h$

This means that the hydrostatic pressure is proportional to the depth of immersion of the immersion probe, i.e. to the height of the liquid column above the measuring point.

Table 1 includes the mean values of h_M / h for the three liquids. Within the limits of the measurement accuracy, they correspond to the numerical values of the densities of the substances in g/cm^3 (see note 2).

Water ρ_w = 1.00 g/cm^3

Alcohol (spirit) ρ_{sp} = 0.85 g/cm^3

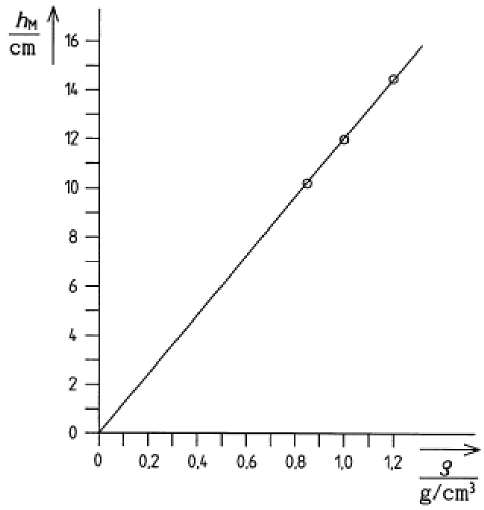
Glycerol ρ_{gl} = 1.20 g/cm^3

In order to prove the proportionality between the pressure p and the density ρ, the values for the height difference h_M are read off in Fig. 2 with the aid of the three straight lines of the liquids and for an immersion depth h = 12 cm. These values are then entered into Table 2. Fig. 3 shows these height differences h_M as a function of the density ρ of the liquids. The result is a straight line that runs through the origin of the system of coordinates or a constant quotient h_M / ρ (see Table 2 and Fig. 3).

Table 2

Substance	h/cm	$\frac{\rho}{g/cm^3}$	h_M/cm	$\frac{h_M/\rho}{cm^4/g}$
Water	12	1.00	12.0	12.0
Alcohol	12	0.85	10.2	12.0
Glycerol	12	1.20	14.5	12.1

Fig. 3



As a result, the following is true:

$$p \sim \rho$$

The experiment shows that the hydrostatic pressure is proportional to the depth of immersion and also to the density.

$$p \sim \rho \cdot h$$

Notes

1. By way of the calculation of the quotients in column 3 of Table 1, this experiment provides exactly the densities of the liquids in g/cm^3 because the pressure measuring instrument is a water-filled U-tube manometer that indicates the pressure in the (old) unit cm WC (centimetre of water column). With a different type of manometer that indicates the pressure hPa, this would not be the case.
2. The hydrostatic pressure p at the depth h results from the force exerted by the weight of the liquid column F_G over the area A:
   $p = F_G / A$
   With the force $F_G = \rho \cdot V \cdot g$ (with g = 9.81m/s^2) and the volume $V = A \cdot h$, the following results:
   $p \sim \rho \cdot g \cdot h$
3. The hydrostatic pressure at the depth h is equal in all directions and it is not dependent on the shape of the measuring probe.

A (homogeneous) liquid has the same level in connected vessels. The first part of the experiment shows that it is independent of the shape of the vessels. The second part of the experiment demonstrates the principle of a flexible tube level (or water level).

Equipment

1	Rod on a magnetic base	02151-02
1	Clamp holder, d = 0…13 mm, on a magnetic base	02151-07
1	Pointers for the demonstration board, 4 pieces	02154-01
1	Efflux vessel for the demonstration board, magnetic	02158-00
1	Immersion probe	02632-00
1	Inclined plane	02152-00
1	Rollercoaster track	02159-00
1	Glass beaker, tall, 600 ml	36006-00
1	Silicone tube, d_i = 6 mm	47530-00
1	Laboratory marker, non-permanent, black	46402-01

Additional equipment

1	Demo physics board with a stand	02150-00
1	Microspoon, stainless steel	33393-00
1	Food colouring, patent blue V	48376-04
1	Set square	

Set-up and procedure 1

- Connect a piece of silicone tube of approximately 1 m to the efflux vessel and position the vessel in the top left-hand area of the demonstration board.
- Position the clamp holder with the immersion probe in the top right-hand area and connect the other end of the tube to the probe (Fig. 1).
- Fill approximately 500 ml of water into the beaker and colour it with the food colouring.

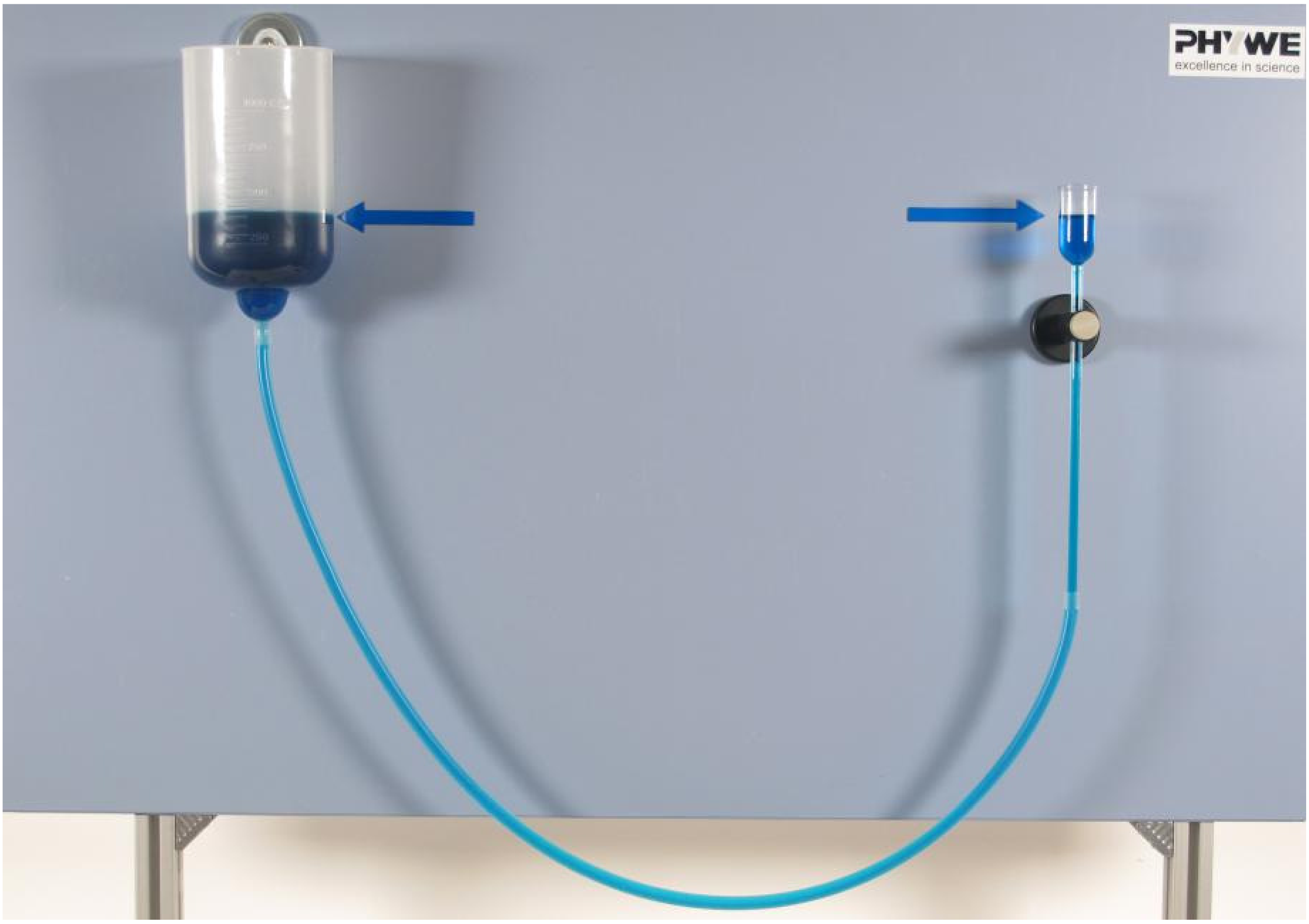


Fig. 1: Experiment set-up 1

- Fill water into the efflux vessel until it can be seen in the glass tube of the immersion probe.
- Remove any trapped air bubbles by squeezing the tube repeatedly.
- Lower the immersion probe or add some more water carefully until the water has risen into the bell-shaped top of the immersion probe (Fig. 1).
- Use the set square to mark the position of the liquid levels on the board with the laboratory marker and accentuate them by way of horizontal pointers.
- Move the immersion probe upwards or downwards or to the sides, incline it to various degrees, and observe the water level.

Observations 1

The liquid levels are always at the same level (on the line that has been drawn), regardless of the position or inclination of the bell-shaped top of the immersion probe.

Evaluation 1

In connected (communicating) vessels, a liquid always stands at the same level. The liquid levels are all on the same horizontal plane.

The reason for this is the hydrostatic pressure (pressure exerted by weight). It is identical in all directions at the lowest point of a system of communicating vessels and it is dependent on the height of the liquid column and not on the shape of the vessels.

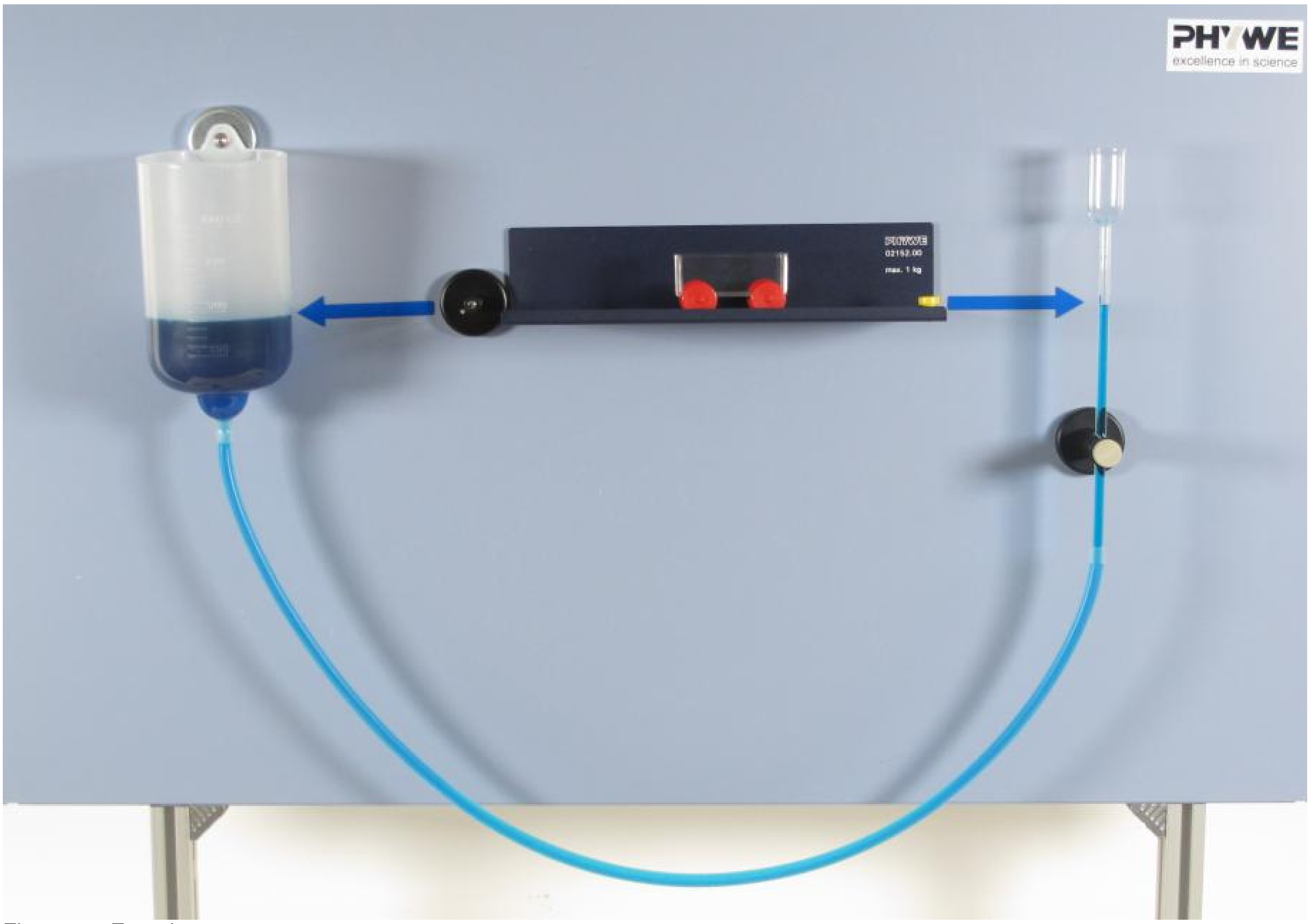


Fig. 2: Experiment set-up 2

Set-up and procedure 2

- Loosen the clamp in the clamp holder and pull the immersion probe upwards so that the water level is located in the glass tube of the probe (Fig. 2).
- Attach the inclined plane, which will be used as a track, horizontally to the board between the two pointers that mark the water levels in the vessels.
- Pull the little yellow screw of the inclined track out as far as possible and position the rod on a magnetic base directly next to the other end of the track. Both the screw and rod are used as stops for the little car.
- Place the little car (included in the scope of supply of the rollercoaster) in the middle of the track and observe it.
- Incline the track to the left and right and observe the car.
  Note: Due to friction, the car should be pushed slightly. Ensure that the inclination is not too small.

Observations 2

The car does not move on a horizontal track. When the track is inclined, it rolls downwards (i.e. it performs an accelerated motion).

Evaluation 2

The second experiment demonstrates an application of communicating vessels: A flexible tube level (water level) can be used to adjust two points that are located at a great distance from each other at the same level. This method is used, for example, for the horizontal alignment of a road track.

Note

Flexible tube levels are mainly used in civil engineering and landscaping. In civil engineering, flexible tube levels can also be used over short distances during the design or renovation of rooms. In landscaping, they are used for levelling over greater distances. In this case, distant points are sighted over the two liquid levels and their difference in height with regard to the horizontal plane of the liquid levels is determined by way of graduated level staffs.

Room for notes

The hydraulic press

MT 6.4

The principle of how a hydraulic system functions is to be worked out on the basis of a model of a hydraulic press.

Materials

Demo-Board Physics	02150.00	1
Torsion dynamometer	03069.03	1
Slotted weight, 50 g, black	02206.01	2
Slotted weight, 50 g, silver bronze	02206.02	2
Fish line, l. 100 m	02090.00	1
Holder for gas syringe with magnetic base	02156.00	2
Gas syringe, 50 ml	02610.00	1
Gas syringe, 100 ml	02614.00	1
Plunger plate for gas syringes	02618.00	2
Silicone hose, i.d. 7 mm	39296.00	1
Commercial weight, 500 g	44096.50	1
Commercial weight, 200 g	44096.20	1
Water soluble pen for overheads		

Experimental set-up

— Prior to the lesson, determine the weight forces F_{K1} and F_{K2} for the plungers with plunger plates, and completely assemble the model of a hydraulic press on the demo-board (see Notes). Position the model so that the plunger plates are at the height of the top of the board (Fig. 1).

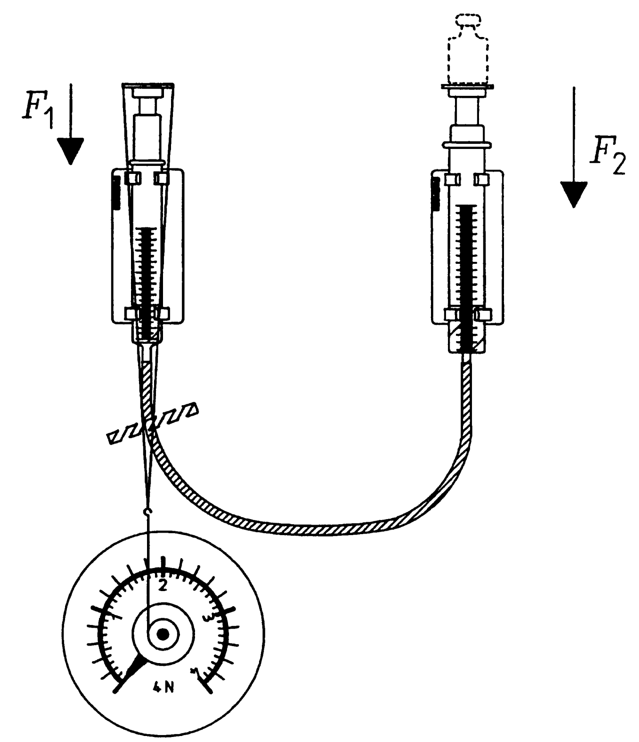
— Position the torsion dynamometer at the lower edge of the board, underneath the 50 ml gas syringe.

— Lay a 50 ... 60 cm length of fishing line over the plunger plate on the 50 ml gas syringe, and lead it further so that the loop formed by the line after fitting it to the dynamometer does not touch any other part of the apparatus. If necessary, fix the silicone tubing to the board with a strip of adhesive tape (Fig. 1).

— Set the dynamometer to zero.

— Use the pen to symbolically denote F_1 and F_2 on the demo-board.

Fig. 1



Procedure

— Note the forces F_{K1} and F_{K2}; bring the students to realize that the system is in equilibrium, and that at first $F_1 = F_{K1}$ and $F_2 = F_{K2}$; enter the values for F_1 and F_2, the forces generating pressure, in Table 1.

— Load the working plunger (the plunger of the 100 ml syringe) with m_B = 100 g ($\triangleq F_B$) and read off from the dynamometer the tractive force F_Z, which is required, together with F_{K1}, for the equilibrium of the system; enter m_B and the value measured for F_Z in Table 1.
Notes: Should the friction between the plungers and the walls of the cylinder be relatively large, we recommend the following procedure: First press one of the plungers by hand and measure F_Z, the force which results when the plunger is let go of. Carry out the same procedure with the other plunger, then calculate the average value for F_Z, and note it.
Because of the relatively large tolerances for the values of F_Z, they should be rounded off to two significant figures. This means that the numerical values for F_B, F_{K1} and F_{K2} should be similarly rounded off. (see Results).

— As a result of the loading of the working plunger with weights of different mass m_B, the force F_B, and so F_2, vary. Measure and enter the force F_Z, which is required each time.

Results

Pressure plunger: A_1 = 4.91 cm² ≈ 4.9 cm²
F_{K1} = 1.03 N ≈ 1.0 N
Working plunger: A_2 = 7.54 cm² ≈ 7.5 cm²
F_{K2} = 1.46 N ≈ 1.5 N

Fig. 2

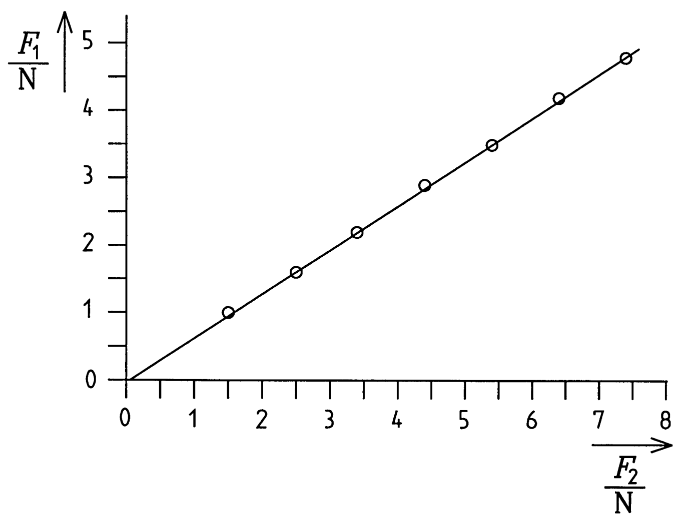


Table 1

m_B/g	F_Z/N	F_B/N	F_2/N	F_1/N	F_1/F_2
0	0.0	0.0	1.5	1.0	0.67
100	0.6	1.0	2.5	1.6	0.64
200	1.2	1.9	3.4	2.2	0.65
300	1.9	2.9	4.4	2.9	0.66
400	2.5	3.9	5.4	3.5	0.65
500	3.2	4.9	6.4	4.2	0.66
600	3.8	5.9	7.4	4.8	0.65

Evaluation

First calculate the values for the force $F_B = m_B g$ and enter them in column 3 of Table 1. Then calculate the forces $F_2 = F_{K2} + F_B$ and $F_1 = F_{K1} + F_Z$ and enter them in columns 4 and 5.
The graph of F_1 as a function of F_2 gives a straight line which passes through the origin (Fig. 2). This means that:

$$F_1 \sim F_2 \quad \text{or} \quad F_1/F_2 = \text{constant}$$

This is confirmed, within the accuracy of the experiment, when the quotient F_1/F_2 is calculated (see Table 1, column 6). The average value is about 0.65. This is the same value as that for A_1/A_2, as A_1/A_2 = 4.9 cm²/7.5 cm² = 0.65. With the hydraulic press, therefore, the forces have the same relationship to each other as the cross-sectional areas on which they work:

$$F_1/F_2 = A_1/A_2\,.$$

From which:

$$F_1/A_1 = F_2/A_2 \quad \text{or} \quad p_1 = p_2\,.$$

The pressure caused by F_1 acts at the same strength everywhere in the incompressible liquid, and so also on the surface area A_2.

Notes

The model of the hydraulic press should be put together before the lesson to save time. To avoid air bubbles in the cylinders or in the connecting tubing to as great an extent as possible, we recommend the following procedure: Press the plunger of the 50 ml gas syringe down to the bottom of the cylinder – hold the nozzle of the syringe under water and fill the cylinder to a height of 2 to 3 cm by drawing back the plunger – turn the syringe upside down, press the plunger as far as it will go into the cylinder, put the holder on the demo-board and clamp the syringe to it; fit an approximately 50 cm length of silicone tubing on the nozzle of the 100 ml sysringe – use the plunger to suck up water until the tubing and two thirds of the cylinder are full of water – turn the syringe upside down, hold the tubing up and depress the plunger so far, that the air bubbles have escaped and the tubing is so full of water, that water begins to run out of it – fit the free end of the tubing on the nozzle of the 50 ml syringe and position the 100 ml syringe on the board with the second holder.

One must accept relatively large measurement errors in this experiment, as forces of friction can be quite large. Errors also occur from the tolerance of the values read off from the dynamometer.

The hydraulic press, just like other hydraulic systems (hydraulic lifts, car brakes etc.), is based on the working principle that one can use a small force F_1 on a pressure piston which has a smaller cross-sectional area A_1 to generate a pressure which exerts a very large pressure force F_2 on a working piston, provided a sufficiently large cross sectional area A_2 has been selected for this.

The hydraulic press

Space for notes

Artesian wells

The principle of an artesian well is to be demonstrated.

Materials

Demo-Board Physics	02150.00	1
Rule for demo-board	02153.00	1
Clip, $d = 0 \ldots 13$ mm, with magnetic base	02151.07	1
Dish, 413 x 120 x 100 mm	47325.01	1
Efflux vessel for Demo Board, magnetic	02158.00	1
Graduated vessel, 1 l, w. handle	36640.00	1
Beaker, 100 ml, low form, plastic	36011.01	1

Set-up and Procedure

— Place the efflux vessel at the top edge of the demo-board. Fit the pinch-cock on the tubing immediately in front of the glass nozzle and close it. Pour about 1000 ml of water into the vessel and squeeze air bubbles out of the tubing.

— Place the dish on the bench below the board.

— Position the clip holding the glass nozzle of the efflux vessel at the lower edge of the board, and align the nozzle, so that it is not exactly vertical.

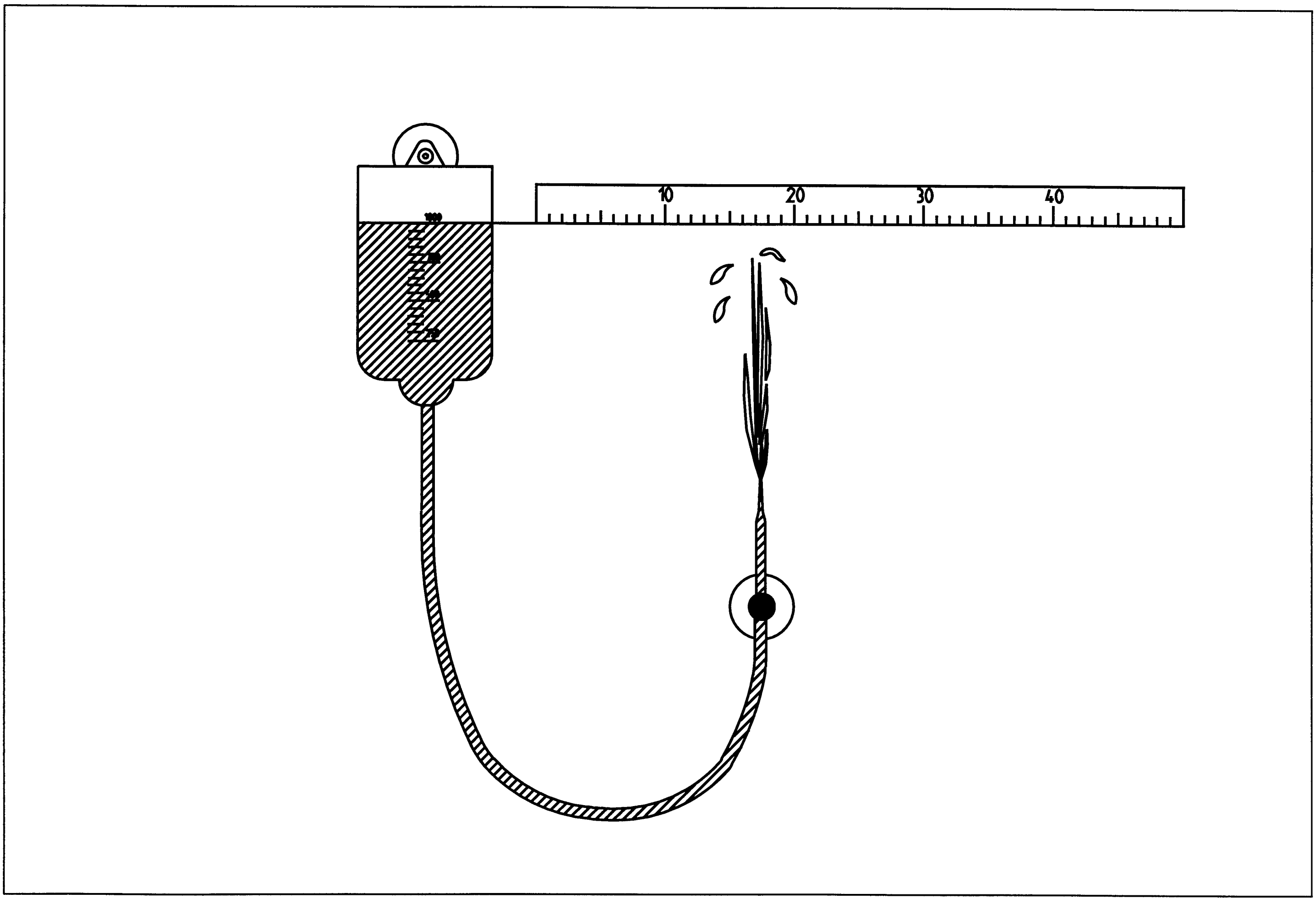
— Position the rule horizontally at the height of the water level (Fig. 1).

— Open the pinch-cock and observe how the water emerges from the "artesian well"; while this is happening, keep pouring water steadily into the efflux vessel, so that the water level changes as little as possible.

Result

The water emerging from the nozzle reaches a height which is below the level of the water in the efflux vessel.

Fig. 1



Artesian wells

Evaluation

The efflux vessel, the glass tube and the connecting tubing form a system of communicating vessels. The water flowing out of the nozzle would, if there was no friction, reach the height of the water level in the efflux vessel.
The pressure of a weight of water is the reason why an artesian well functions. Frictional forces are the reason why the fountain does not reach the height of the water level.

Notes

The glass nozzle should not be exactly vertical, because then the emerging water would fall back on itself and less height would be attained.
It is advisable to place a large, absorbent cloth under the board to absorb splashes of water.
When underground water can collect between two layers of earth which are impermeable to water, and the layers form a basin, then, on boring through the upper layer into the basin (in the valley), water under pressure emerges from the earth. Wells made in this way are named artesian wells, after the French count's land Artois, where, according to historical documents, such wells were in use as early as the 12th Century.

Archimedes' Principle

It is to be shown first that a solid body immmersed in a liquid is buoyed up, and then how the buoyant force can be calculated.

Materials

Demo-Board Physics	02150.00	1
Torsion dynamometer	03069.03	1
Shelf, magnetically held	02155.00	1
Hollow and solid cylinder	02636.00	1
Glass beaker, tall, 600 ml	36006.00	1
Beaker, 100 ml, low form, plastic	36011.01	1
Food colour Patent Blue V (E131)	48376.04	1
Microspoon, special steel	33393.00	1

Set-up and Procedure

— Fit the torsion dynamometer onto the demo-board.

— Demonstrate that the hollow cylinder exactly fills the solid cylinder.

— Hang the hollow cylinder on the dynamometer and set the dynamometer to zero.

— Hang the solid cylinder on the hollow cylinder and determine the weight force $F_{G,L}$ of it; note $F_{G,L}$ (1).

— Position the shelf at the lower edge of the demo-board and place the glass beaker containing 400 ml of coloured water on it (Fig. 1).

— Lower the dynamometer until the solid cylinder is completely immersed in the water; measure $F_{G,W}$ and note the value of it (2).

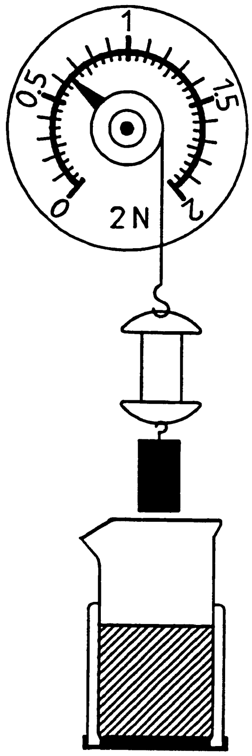
— Pour about 50 ml of coloured water into the beaker, and so much in the hollow cylinder, that it is full to the brim.

— Measure the weight force FG now displayed and note it (3).

Results

(1)	$F_{G,L}$	=	0.64 N
(2)	$F_{G,W}$	=	0.20 N
(3)	F_G	=	0.64 N

Fig. 1



Archimedes' Principle

Evaluation

The pulling force which the solid cylinder exerts on the dynamometer is $F_{G,L}$ = 0.64 N in air, and decreases on lowering the solid cylinder into water by 0.44 N. The cause of this is the buoyant force F_A which is in effect in water and is directed from vertically below, i.e. opposite to the weight force.

When the solid cylinder is completely immersed in water, the buoyant force is exactly the same as the weight force which acts on the water that the hollow cylinder contains. This is, however, exactly the weight force of the water displaced by the solid cylinder.

We therefore have:

$$F_A = F_{G,L} - F_{G,W} ,$$

and because

$$V_{hollow} = V_{solid} = V_W = V_{Fl}$$

we have:

$$F_A = V_K \cdot \rho_{FL} \cdot g$$

where

V_K	=	The volume of the immersed body
	=	The volume of displaced liquid,
ρ_{FL}	=	The density of the liquid,
g	=	The acceleration due to gravity.

The formula for F_A is called Archimedes' Law (traditionally Archimedes' Principle): The buoyant force acting on a body immersed in a liquid is equal to the weight force of the liquid displaced by the body.

Notes

The buoyant force F_A results from the pressure forces which act on the immersed body and are proportional to the height of the liquid column. The pressure forces acting sideways on the body compensate each other. The upwardly directed pressure force F_u which acts on the bottom boundary area is larger than that acting on top F_o. These areas are equal for the solid cylinder, so that:

$$F_A = F_u - F_o = p_u \cdot A - p_o \cdot A = (p_u - p_o) \cdot A .$$

Because $p = \rho \cdot g \cdot h$ it follows that, in general for the upwardly directed buoyant force:

$$F_A = \rho \cdot g \cdot A\,(h_u - h_o) = \rho \cdot g \cdot A \cdot h ,$$

where h is the height of the cylinder.

We therefore have:

$$F_A = \rho \cdot g \cdot V = \rho_{Fl} \cdot g \cdot V_K .$$

Archimedes' Law is also valid when only a part of the body is immersed in a liquid. Using ΔV_K as the volume of the immersed part, we have:

$$F_A = \Delta V_K \cdot \rho_{FL} \cdot g .$$

A body

sinks down in the liquid, when	F_A	$<$	$F_{G,L}$,
rises up in the liquid, when	F_A	$>$	$F_{G,L}$,
floats, when	F_A	$=$	$F_{G,L}$ and
swims, when	F_A	$=$	$\Delta V_K \cdot \rho_{FL} \cdot g$
		$=$	$F_{G,L}$.

Determination of density by measurement of the buoyancy

MT 6.7

It is to be shown, how the density of solid and liquid substances can be determined from a measurement of the buoyancy.

Materials

Demo-Board Physics	02150.00	1
Torsion dynamometer	03069.03	1
Shelf, magnetically held	02155.00	1
Sinker, aluminium	03903.01	1
Glass beaker, tall, 600 ml	36006.00	1
Glycerol 250 ml	30084.25	2

Set-up and Procedure 1

— Fasten the torsion dynamometer at the upper edge of the demo-board.
— Hang the sinker on, measure the weight force of it in air ($F_{G,L}$) and note this value.
— Position the shelf underneath the sinker at the lower edge of the board, then place the glass beaker containing about 400 ml of water on it (Fig. 1).
— Lower the dynamometer with sinker, until the sinker is completely immersed in the water.
— Measure the weight force $F_{G,W}$ with which the sinker now pulls on the dynamometer, and note this value.

Results 1

$F_{G,L}$ = 2.15 N
$F_{G,W}$ = 1.35 N

Evaluation 1

The buoyant force acting on the immersed body is:

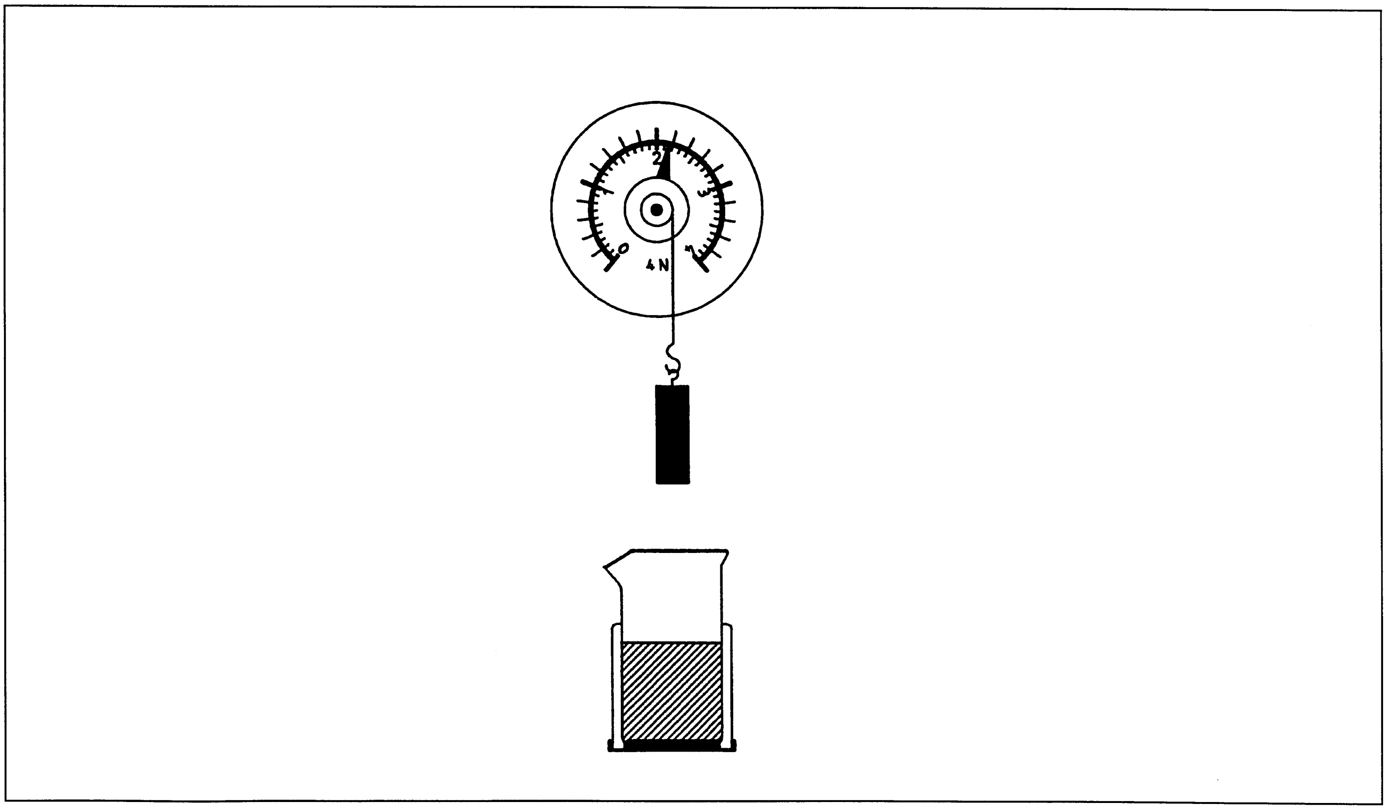
$$F_A = F_{G,L} - F_{G,W} = 0.80 \text{ N}$$

According to Archimedes' Law, F_A is equal to the weight force of the water displaced by the body. The mass of the displaced water is therefore m_W = 82 g (1 N ≙ 102 g), and the volume of it V_W = 82 cm^3. The volume of the immersed body is therefore $V = V_W$ = 82 cm^3, and, as $F_{G,L}$= 2.15 N, the mass is m = 219 g.
From this we can calculate the sought-after density of aluminium

$$\rho = m / V = 219 \text{ g}/82 \text{ cm}^3 = 2.7 \text{ g/cm}^3.$$

This corresponds to the value given in Tables.

Fig. 1



Determination of density by measurement of the buoyancy

Notes 1

To make the evaluation easier, we can assume as a simplification and within the accuracy of the measurement, that 1 N corresponds to the weight force which acts on a body of mass $m = 100$ g:

F_A = 0.80 N –> m_W = 80 g –> $V_W = V = 80$ cm³;
$F_{G,L}$ = 2.15 N –> m = 215 g
$\rho = m/V = 215$ g/80 cm³ = 2.7 g/cm³.

If the students are not aware that the sinker is made of aluminium, the experiment can also be used, alongside the determination of ρ, to discover from which substance the sinker is made of. In this case, cover the symbol on the sinker e.g. with a sticker, prior to the experiment.

Set-up and procedure 2

— Use the set-up as in Experiment 1, but pour alcohol into the glass beaker instead of water.
— Lower the dynamometer, with the sinker hung on it, until the sinker is completely immersed in the alcohol.
— Measure the weight force $F_{G,Sp}$ with which the sinker pulls on the dynamometer and note this value.
— Replace the alcohol in the beaker with glycerol and carry out the same procedure to measure and note the force $F_{G,Gl}$.

Results 2

$F_{G,Sp}$ = 1.47 N
$F_{G,Gl}$ = 1.19 N
$F_{G,L}$ = 2.15 N
V = 82 cm³

Evaluation 2

The value measured for $F_{G,L}$ in experiment 1, and that calculated for the volume $V (= V_W = V_{Sp} = V_{Gl})$, are to be taken as results here.

Now calculate the buoyant force F_A for alcohol and for glycerol, from these the mass of the liquid displayed in each case and finally the densities of the test substances. It is of advantage to enter all of the results from Experiment 1 and Experiment 2 together in a Table:

$m = F_G/g$,
$\rho = m/V$

Liquid	V/cm³	F_A/N	m/g	$\frac{\rho}{g/cm^3}$
Water	82	0.80	82	1.00
Alcohol	82	0.68	69	0.84
Glycerol	82	0.96	98	1.20

The results agree well with values given in Tables of Densities, within the measurement accuracy:
ρ_{Sp} = 0.85 g/cm³
ρ_{Gl} = 1.20 g/cm³

Notes 2

As mentioned in Note1, the measured data can be subjected to a simplification, because of the inaccuracies in the measurement which are present anyway.
We obtain
for alcohol: $\rho = 68$ g/80 cm³ = 0.85 g/cm³
and for glycerol: $\rho = 96$ g/80 cm³ = 1.20 g/cm³
When Experiment 2 is to be carried out independently of Experiment 1, the volume of the body which is immersed must be determined by dimensional measurement and calculation, when it has a regular shape. Should this not be the case, it must be determined by a displacement method (difference or overflow method).

Speed of outflow from a vessel

The behaviour of the speeds at which water flows out of a vessel through outlets at various heights is to be examined.

Materials

Demo-Board Physics	02150.00	1
Pointer for demo-board, 4 pcs	02154.01	1
Point markers for demo-board, 24 pcs	02154.02	1
Clip, $d = 0 \dots 13$ mm, with magnetic base	02151.07	1
Dish, 413 x 120 x 100 mm	47325.01	1
Efflux vessel for Demo Board, magnetic	02158.00	1
Graduated vessel, 1 l, w. handle	36640.00	1
Water soluble pen for overheads		

Experimental set-up

— Position the efflux vessel top left on the white, gridded side of the demo-board. Fit the tube clamp on the tubing immediately in front of the glass nozzle and tighten it. Pour 100 ml of water into the vessel and press air bubbles out of the tubing by squeezing it.

— Draw the ouline of an imaginary larger vessel, which is to be represented by the efflux vessel, on the board (Fig. 1).

— Use pointers to mark the water level, as well as suitable positions where the outlets are intended to be.

— Place a dish on the bench beneath the board.

— Adjust the position of the magnetic clip holding the glass nozzle of the efflux vessel on the board, that the nozzle is held horizontally with its tip ending at one of the marked outlets.

Procedure

— Open the tube clamp and mark the path of the water with marking points all having the same colour.

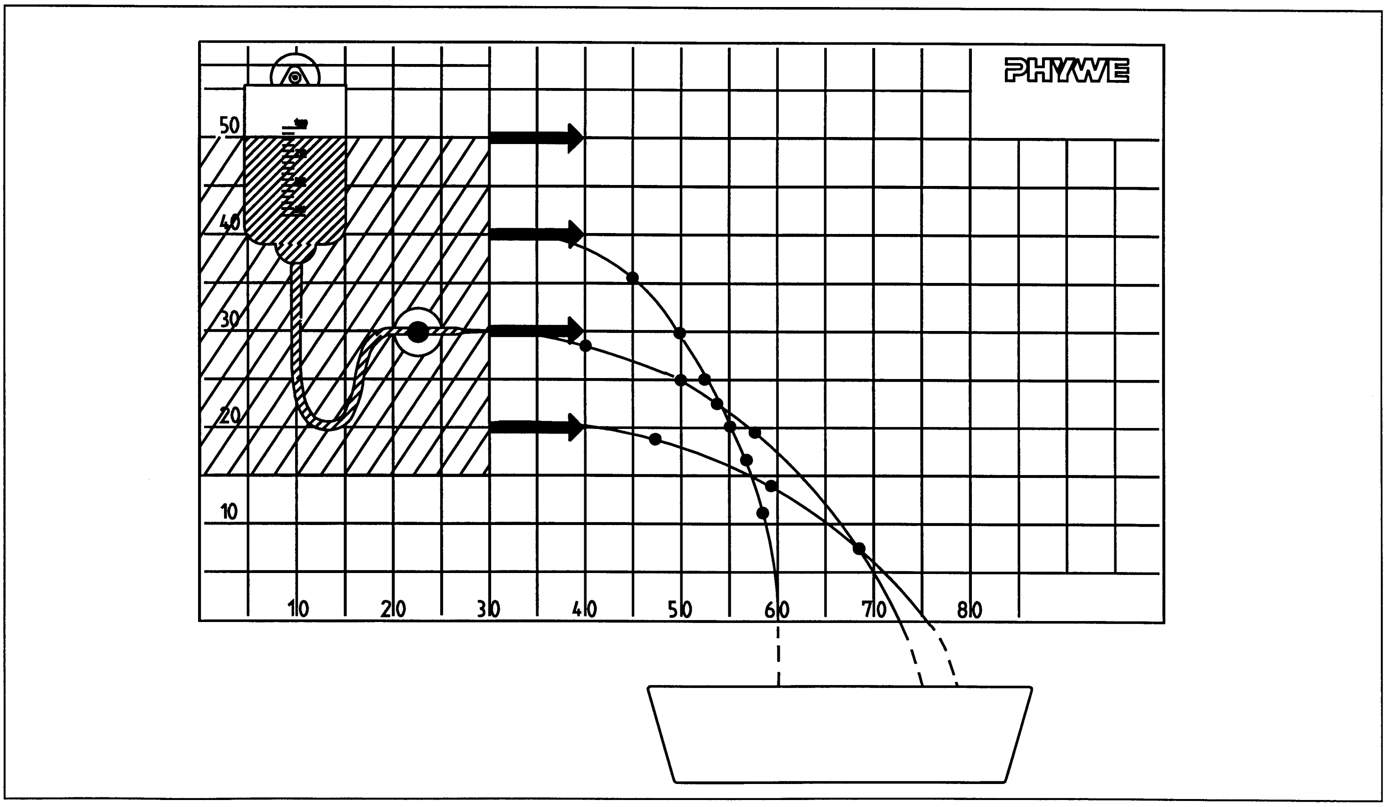
— Close the tube clamp and pour the discharged water back into the efflux vessel.

— Move the clamp with glass nozzle to the second, then the third, outlet and proceed in the same way as above for each, again marking the paths with points of a single colour.

Result

The lower the outlet, the further away from the vessel the jet of water travels, i.e. the higher the speed at which the water emerges from the nozzle.

Fig. 1



Speed of outflow from a vessel

Evaluation

Use the pen to draw lines on the board through the points which mark the paths over which the water has travelled (as indicated in Fig. 1). They give parabolas, which bulge more the lower the outlet.

The pressure of the weight above the outlet, which is proportional to the height h of the water column above the outlet:

$$p = \rho \cdot g \cdot h\,.$$

is the cause of the higher outflow speed the lower the outlet is situated.

Because of

$$F = p \cdot A = \rho \cdot g \cdot h \cdot A$$

a pressure force F which is proportional to the depth h acts on the water as it emerges, accelerating the water particles and so determining their speed.

This pressure force is indeed also proportional to the area A, but this has no effect on the speed at which the water emerges, as with increasing cross-sectional area A, the mass of water which the pressure accelerates per unit time also increases.

Notes

Only a little water emerges from the vessel per unit time, because the nozzle opening is small, and when the observation times are kept relatively short, the water level in the efflux vessel does not change very much during the length of observation. It therefore suffices, to pour back the water after the observation.

The use of the white side of the board is not absolutely necessary in this experiment, but it does offer several benefits, e.g. it helps when drawing in the large imaginary vessel and positioning the outlets and the nozzle.

It is advisable to place a large, absorbent cloth under the board to absorb splashes of water.

Pressure in gases

MT 6.10

An enclosed amount of gas is to be compressed by the pressure of a plunger, and an investigation is to be made as to which relationship thereby exists between the pressure of the gas and the pressure force acting on a defined area.

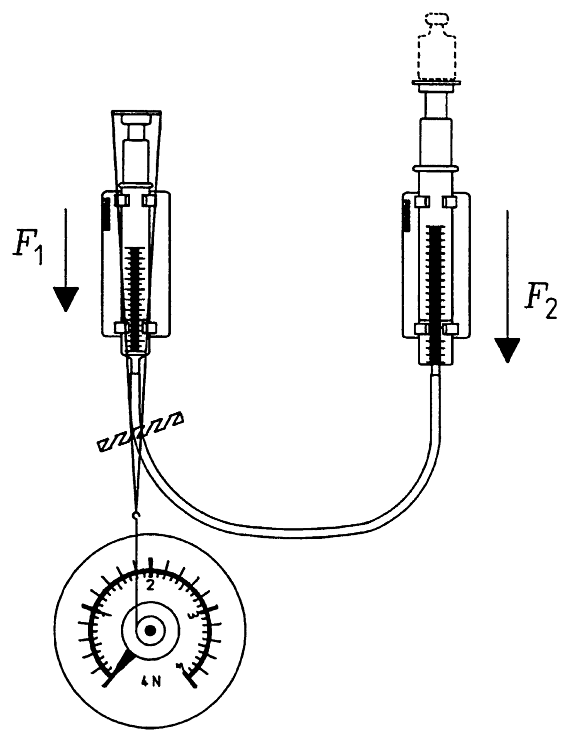
Materials

Demo-Board Physics	02150.00	1
Torsion dynamometer	03069.03	1
Holder for gas syringe with magnetic base	02156.00	2
Gas syringe, 50 ml	02610.00	1
Gas syringe, 100 ml	02614.00	1
Plunger plate for gas syringes	02618.00	2
Silicone hose, i.d. 7 mm	39296.00	1
Slotted weight, 50 g, black	02206.01	2
Slotted weight, 50 g, silver bronze	02206.02	2
Commercial weight, 500 g	44096.50	1
Commercial weight, 200 g	44096.20	1
Fish line, 1 m from	02090.00	
Water soluble pen for overheads		

Experimental set-up

— Use the holders to position the gas syringes, with plungers removed, at the top edge of the demo-board.
— Connect the syringes with an approximately 50 cm length of silicone tubing.
— Use the dynamometer to determine the weight forces F_{K1} and F_{K2} for the plungers, each inclusive plunger plate, and note the values.
— Push the plunger of gas syringe 1 (50 ml) completely in, right down to the bottom.
— Push the plunger of gas syringe 2 (100 ml) so far in the cylinder, until the bottom surfaces of the two plungers are at about the same height.
— Make a loop from the fishing line which is sufficiently large to fit over the plunger plate of syringe 1.
— Position the torsion dynamometer so underneath syringe 1, that after hooking it to the loop, the loop touches neither the tubing nor the syringe or its holder, and the dynamometer is set to zero. If necessary, fix the silicone tubing to the board with a strip of adhesive tape.
— Use the pen to symbolically denote F_1 and F_2 on the demo-board (Fig. 1).

Fig. 1



Procedure

- Make clear, that the system is in equilibrium; enter the forces $F_2 = F_{K2}$ and $F_1 = F_{K1}$ in Table 1.
- Load plunger 2 with m_B = 200 g.
- Balance out the two plungers to some extent by hand, to lessen the unavoidable frictional forces between the plungers and the cylinders.
- Read off from the dynamometer the tractive force F_Z, which is required, together with F_{K1}, for the equilibrium of the system; enter F_Z in Table 1.
  Note: The determination of F_Z should be carried out quickly, particularly with heavy loads, because the plungers can keep sliding down somewhat.
  Because of the relatively large tolerances for the values of F_Z, it is judicous to round them off to two significant figures. When this is done, the numerical values for F_B, F_{K1} and F_{K2} must be similarly rounded off.
- Vary the load on plunger 2, determining the corresponding values for force F_2 and noting them.

Results

F_{K1} = 1.03 N ≈ 1.0 N
F_{K2l} = 1.46 N ≈ 1.5 N
A_1 = 4.91 cm² ≈ 4.9 cm²
A_2 = 7.54 cm² ≈ 7.5 cm²
A_1/A_2 = 0.65

Table 1

Load on plunger 2 m_B/g	F_B/N	F_Z/N	F_2/N	F_1/N	F_1/F_2
0	0.0	0.0	1.5	1.0	0.67
200	2.0	1.2	3.5	2.2	0.63
300	2.9	1.8	4.4	2.8	0.64
400	3.9	2.5	5.4	3.5	0.65
500	4.9	3.1	6.4	4.1	0.64
600	5.9	3.7	7.4	4.7	0.64

Evaluation

Determine the cross-sectional areas of the plungers, A_1 and A_2 by measurement and calculation (if they are not provided) and note them. Enter the quotient A_1/A_2 below them.

Calculate the values for F_B according to $F_B = m_B \cdot g$, round them off and enter them in Table 1, column 2.
Use the formulas $F_2 = F_{K2} + F_B$ and $F_1 = F_{K1} + F_Z$ to calculate the forces which act on the plungers. Note them in Table 1, columns 4 and 5.
The graphical representation of $F_1 = f(F_2)$ gives a straight line which passes through the origin, within the accuracy of the measurement (Fig. 2). It follows from this, that $F_1 \sim F_2$ or F_1/F_2 = constant, in agreement with the figures for the quotient F_1/F_2 in the last column of Table 1.
The average value for the quotient F_1/F_2 is almost 0.65. The quotient A_1/A_2 has the value 0.65, so that:

$$F_1/F_2 = A_1/A_2$$
or
$$F_1/A_1 = F_2/A_2$$
or
$$p_1 = p_2.$$

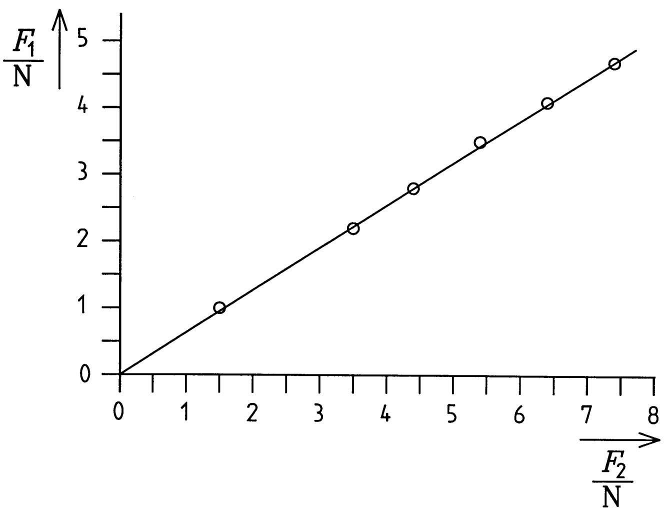
When pressure is exerted on an enclosed amount of gas, the gas pressure is the same everywhere:

$$p = F_1/A_1 = F_2/A_2 = ... = F_n/A_n.$$

Note

The experiment is not successful when there is noticeable friction between the plungers and the cylinders of the gas syringes, or when the plungers do not close well. To remedy this, thoroughly clean the sliding surfaces with a liquid which dissolves fat, e.g. alcohol, and lightly lubricate the plungers, e.g. with glycerol.

Fig. 2



The Boyle-Mariotte Law

MT 6.11

The relationship which exists between the pressure and the volume of an enclosed gas on compressing it is to be determined.

Materials

Demo-Board Physics	02150.00	1
Torsion dynamometer	03069.03	1
Holder for gas syringe with magnetic base	02156.00	1
Gas syringe, 50 ml	02610.00	1
Plunger plate for gas syringes	02618.00	1
Rubber caps, pack of 20	02615.03	1
Commercial weight, 1000 g	44096.70	1
Commercial weight, 500 g	44096.50	1
Commercial weight, 200 g	44096.20	1

Set-up and Procedure

— Fix the holder for gas syringes on the demo-board and clamp in the 50 ml gas syringe, so that the scale is at the front (Fig. 1).

— Measure the weight force F_K for the plunger plus plunger plate with the torsion dynamometer, and note the value obtained.

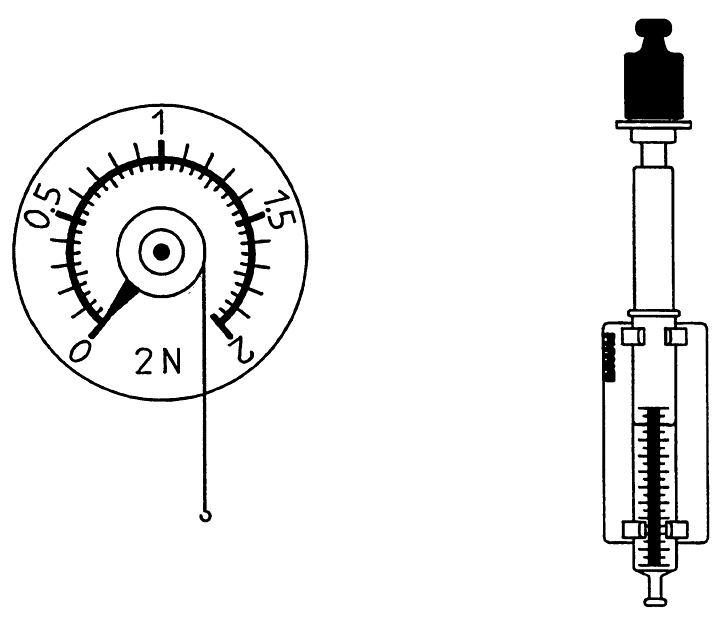
— Insert the plunger with the plunger plate in the cylinder of the syringe and so hold it, that the mark at its lower end is at exactly the same height as the 50 ml mark of the left scale on the cylinder. Fit a rubber cap on the syringe outlet: Enter the initial volume $V = V_0 = 50$ ml in the first column of Table 1.

— Let go of the plunger and read the volume V which the enclosed gas now occupies. Enter V in the second line of Table 1.
Note: Because friction between the plunger and the cylinder canot be avoided, it is fitting to balance out the plunger by carefully moving it a little by hand, before reading V. This should be performed quickly, however, as, particularly with heavy loads, the plunger slides further down, because the syringe cannot be made completely air-tight.

— Remove the rubber cap and slide the plunger back to its initial position, load it with the weight of mass $m_B = 200$ g ($\triangleq F_B$). Put the cap on the outlet, let go of the plunger and determine V as previously; enter m_B and V.

— Load the plunger with various weights m_B and determine each of the volumes V as above; enter m_B and V.

Fig. 1



Results

F_K = 1.03 N
A = 4.9 cm^2
V_0 = 50 cm^3

Table 1

m_B / g	V / cm^3	F_B / N	p_B / N/cm^2	p / N/cm^2	$p \cdot V$ / Ncm
0	50	0.00	0.0	10.1	505
0	49	0.00	0.0	10.3	505
200	47	1.96	0.4	10.7	503
500	44	4.90	1.0	11.3	497
700	43	6.86	1.4	11.6	503
1000	41	9.80	2.0	12.3	504
1200	40	11.76	2.4	12.7	508
1500	38	14.70	3.0	13.3	505

Evaluation

Enter the weight forces $F_B = F_B \cdot g$, which correspond to the masses m_B with which the plunger was loaded with, in Table 1, column 3.

From this, we have for the pressure:

$$p_B = F_B/A$$

(column 4). The cross-sectional area of the plunger A is either provided or determined by measurement and calculation: A = 4.9 cm^2.

Now calculate the pressure which prevails in the enclosed gas:

$$p = p_0 + p_K + p_B \text{ where}$$

p_0 = external air pressure; here we can use, within the accuracy of the experiment, the value for standard pressure (10.13 N/cm^2), so that
p_0 = 10.13 N/cm^2 ≈ 10.1 N/cm^2
p_K = the pressure generated by the plunger and plunger plate, which is
p_K = F_K/A = 1.03 N/4.9 cm^2 = 0.21 N/cm^2

It is to be seen from the 2nd and 5th column in Table 1, that, as is to be expected, the volume V is smaller, when the pressure is greater. We can assume, that p and V behave inversely proportional to each other. The product $p \cdot V$ must then have a constant value. The calculation of the products confirms this assumption, within the accuracy of the measurement. (see Table 1, last column).
For an enclosed gas, we therefore have:

$$p_0 \cdot V_0 = p_1 \cdot V_1 = \dots = p_n \cdot V_n = \text{constant}$$

or, in general:

$$p \cdot V = \text{constant.}$$

This law, known as the Boyle-Mariotte Law, is valid under the condition, that the temperature T of the gas remains constant when the gas is compressed, which is true to a large degree in the experiment.

Note

The experiment is not successful when there is noticeable friction between the plungers and the cylinders of the gas syringes, or when the plungers do not close well. To remedy this, thoroughly clean the sliding surfaces with a liquid which dissolves fat, e.g. alcohol, and lightly lubricate the plungers, e.g. with glycerol.