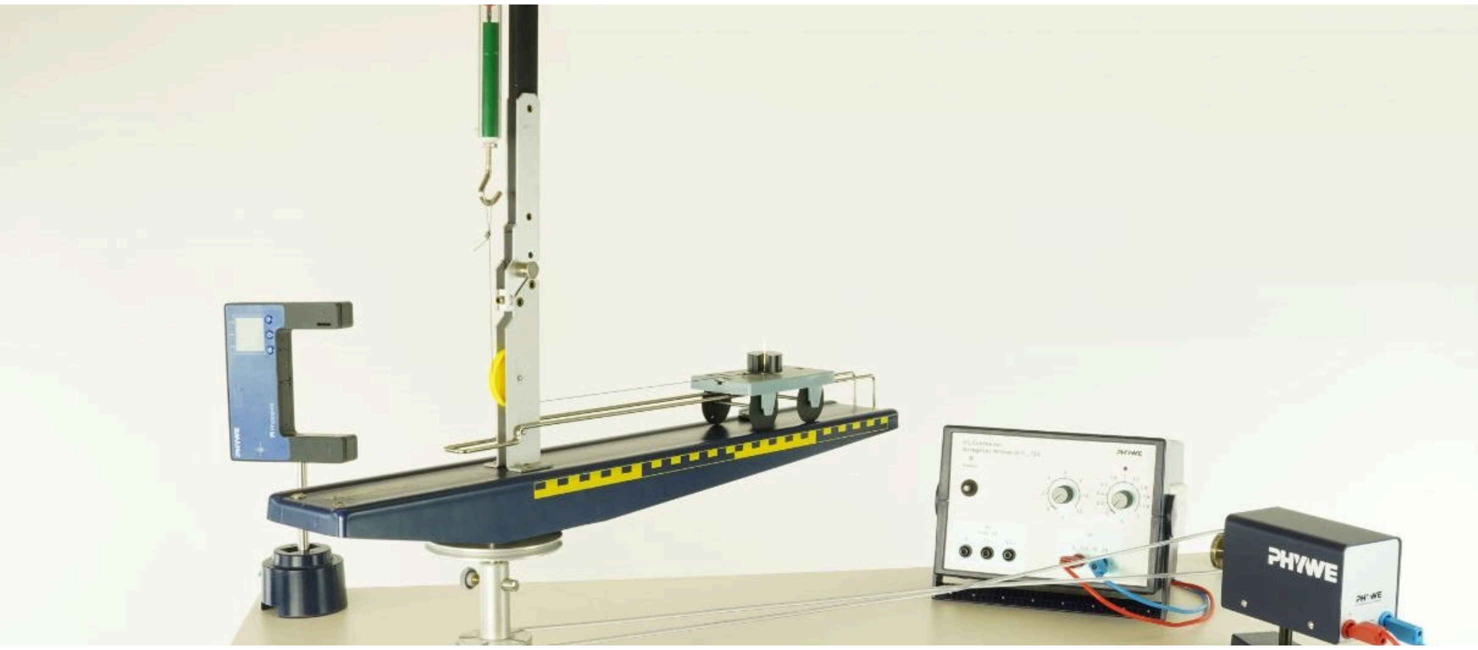
# Centrifugal force




The goal of this experiment is to understand the centrifugal force.

| Physics | Mechanics | Circular motion & rotation |
|---|---|---|

| Difficulty level | Group size | Preparation time | Execution time |
|---|---|---|---|
| hard | 2 | 10 minutes | 20 minutes |

This content can also be found online at:

http://localhost:1337/c/606c1974e54a2f0003f6b31d

# General information

## Application

Experimental setup

Centrifuges are used in science and industry to separate substances. In the reference frame spinning with the centrifuge, the centrifugal force induces a hydrostatic pressure gradient in fluid-filled tubes oriented perpendicular to the axis of rotation, giving rise to large buoyant forces which push low-density particles inward.

Elements or particles denser than the fluid move outward under the influence of the centrifugal force. This is effectively Archimedes' principle as generated by centrifugal force as opposed to being generated by gravity.



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## Other information (1/2)

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**Prior knowledge**

There is no prior knowledge necessary.

**Main principle**

A body with variable mass moves on a circular path with adjustable radius and variable angular velocity. The centrifugal force of the body will be measured as a function of these parameters.

## Other information (2/2)

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**Learning objective**

The goal of this experiment is to understand the centrifugal force.

**Tasks**

Determination of the centrifugal force as a function

1. of the mass,
2. of the angular velocity,
3. of the distance from the axis of rotation to the centre of gravity of the car.



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## Theory

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In the reference system which rotates with the angular velocity $\vec{\omega}$, the equation of motion of a mass point (mass m, position vector $\vec{r}$) reads:

$$m\frac{d\vec{v}}{dt} = -\nabla U + m\vec{r} \times \frac{d\vec{\omega}}{dt} + 2m\vec{v} \times \vec{\omega} + m\vec{\omega} \times (\vec{r} \times \vec{\omega}) - \vec{F} \quad (1)$$

The external force field U (gravitational field) is compensated by the track, the angular velocity $\omega$ is constant, and the car is at rest in the rotating reference system $U = 0; \vec{v} = const. = 0; \vec{\omega} = 0$ .

From (1), there only remain the centrifugal force and the compensating force $\vec{F}$, which is read on a spring balance:

$$\vec{F} = m\vec{\omega} \times (\vec{r} \times \vec{\omega})$$

since $\vec{r} \perp \omega$, it follows that

$$|\vec{F}| = m\omega^2 \cdot r \qquad (2)$$



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## Equipment

| Position | Material | Item No. | Quantity |
|---|---|---|---|
| 1 | Centrifugal force apparatus | 11008-00 | 1 |
| 2 | Cart for measurements and experiments | 11060-00 | 1 |
| 3 | Holding pin | 03949-00 | 1 |
| 4 | Motor with disk holder | 11614-00 | 1 |
| 5 | Bearing unit | 02845-00 | 1 |
| 6 | Driving belt | 03981-00 | 1 |
| 7 | Support rod with hole, stainless steel, 10 cm | 02036-01 | 1 |
| 8 | Barrel base expert | 02004-00 | 1 |
| 9 | Spring balance holder | 03065-20 | 1 |
| 10 | Spring balance,transparent, 2 N | 03065-03 | 1 |
| 11 | Support rod, stainless steel, l = 250 mm, d = 10 mm | 02031-00 | 1 |
| 12 | Bench clamp expert | 02011-00 | 2 |
| 13 | Fish line, l. 100m | 02090-00 | 1 |
| 14 | Slotted weight, silver bronze, 10 g | 02205-03 | 4 |
| 15 | Slotted weight, silver bronze, 50 g | 02206-03 | 2 |
| 16 | Cobra SMARTsense Dual Photogate - Double light barrier 0 ... ∞ s (Bluetooth + USB) | 12945-00 | 1 |
| 17 | Connecting cord, 32 A, 1000 mm, red | 07363-01 | 1 |
| 18 | Connecting cord, 32 A, 1000 mm, blue | 07363-04 | 1 |
| 19 | PHYWE Power supply, 230 V, DC: 0...12 V, 2 A / AC: 6 V, 12 V, 5 A | 13506-93 | 1 |



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# Setup and Procedure

## Setup

The experimental set-up is arranged as shown in Fig. 1. The red pointer supplied should be fitted on the central rod of the car. It indicates the distance (axis of rotation to centre of gravity of car). At the outermost end of the centrifugal apparatus, a mask is glued between the guide rods and serves for the start-stop triggering of the light barrier. When measuring the duration of a complete cycle switch to “ ”-mode. Ensure that the car does not touch the light barrier at maximum radius.

With increasing angular velocity, the radius increases, since the force measurement involves movement. This should be compensated by moving the spring balance up and downwards.

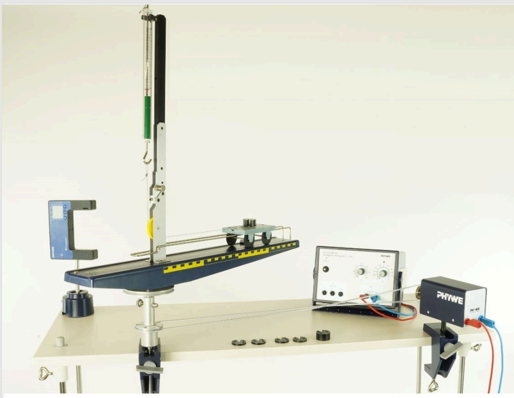

Fig. 1: Experimental set-up for the measurement of centrifugal force.



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## Procedure (1/3)

**Determination of the centrifugal force as the function of mass.**

The experimental car is gradually loaded with the additional weights. The centrifugal force apparatus with a constant angular velocity is rotated with each given mass m. The force occurring $F_z$ is determined with the help of a spring balance. The car is connected below the pulley to a spring balance by a thread (approx. 26 cm in length) and a decoupling hook. The spring balance is pushed down to the maximum possible position. Now a constant angular velocity is set to the motor, which remains constant during the entire course of the experiment.
The force $F_z$ experienced by the measuring car without any additional weight is read. The position r of the red pointer is marked by a piece of adhesive tape. For this purpose, the motor is stopped by switching off. The additional weights are placed on the measuring car and the spring balance is pushed up till the car stands a little before the pulley. The motor is switched on. By fixing the spring balance in the upper range, it is possible to move it down (at intervals of approx. 1 cm). By this, the indicator on the measuring car approaches the marked position ‘r’. When its position is reached, the respective force $F_z$ is read.

## Procedure (2/3)

**Determination of the centrifugal force as a function of angular velocity.**

The mass of the experimental car stays constant in this part of the experiment. A predetermined radius (e.g. r = 20 cm) is marked with a piece of adhesive tape. At different angular velocities by means of displacement of the spring balance as in part 1, the measuring car is brought to position r. Push the car from inside to the outside. The respective forces $F_z$ are read. The angular velocity $\vec{\omega}$ is calculated from the time of rotation T.

$\omega = 2\pi/T$



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## Procedure (3/3)

**Determination of the centrifugal force as the function of distance of the axis of the rotational centre.**

The mass of measuring car remains constant. A fixed angular velocity is set to the motor. The radius of the orbit r of the measuring car is increased by means of displacement of the spring balance and the respective centrifugal force $F_z$ and the radius r are measured.

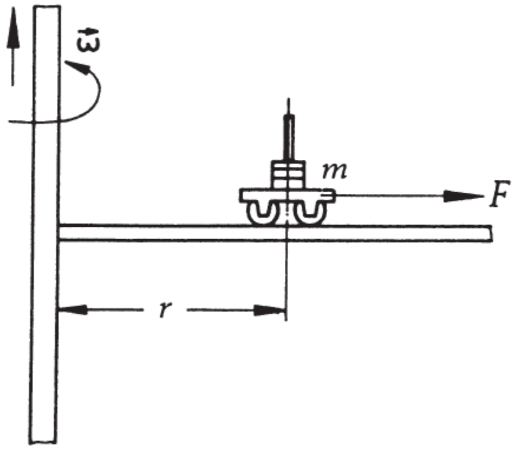


Fig. 2: Mass m, at rest in the rotating reference system.

# Evaluation



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## Evaluation (1/3)

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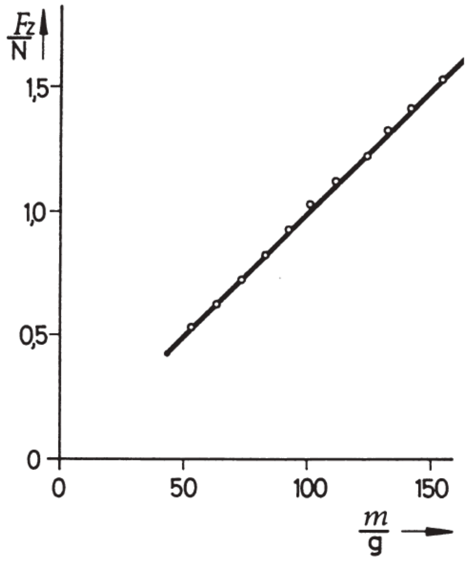
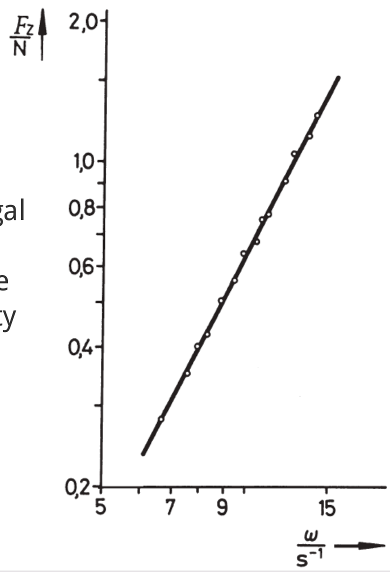



Fig. 3: Centrifugal force as a function of the mass m.

Fig. 4: Centrifugal force as a function of the angular velocity $\omega$.




## Evaluation (2/3)

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From the regression line to the measured values of Fig. 4, with the exponential statement

$$Y = A \cdot X^B + Y_0$$

the exponent is obtained $B = 2.053$

**Note**

The spring balance used to measure the centrifugal force follows Hooke's law:

$$F_D = -k \cdot r$$

where k is the spring constant. Since the centrifugal force is also linear with respect to r:

$$F = m\omega^2 r$$



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## Evaluation (3/3)

a distinction must be made between three cases:

1. Stable condition for $k > m\omega^2$
2. Neutral condition for $k = m\omega^2$
3. Unstable condition for $k < m\omega^2$

For safety reasons, the unstable condition should be avoided in the experiment.

Also, the range $k \approx m\omega^2$ is unsuitable for the measurement because of the inaccuracies which occur.

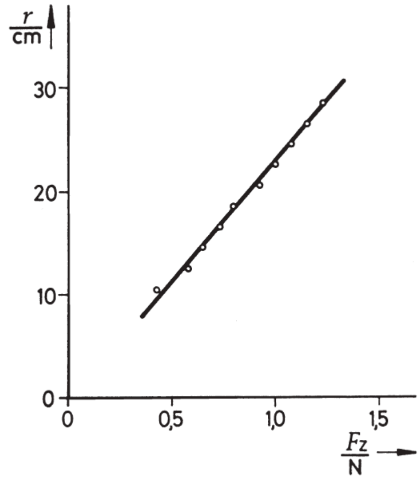


Fig. 5: Centrifugal force as a function of the radius.



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