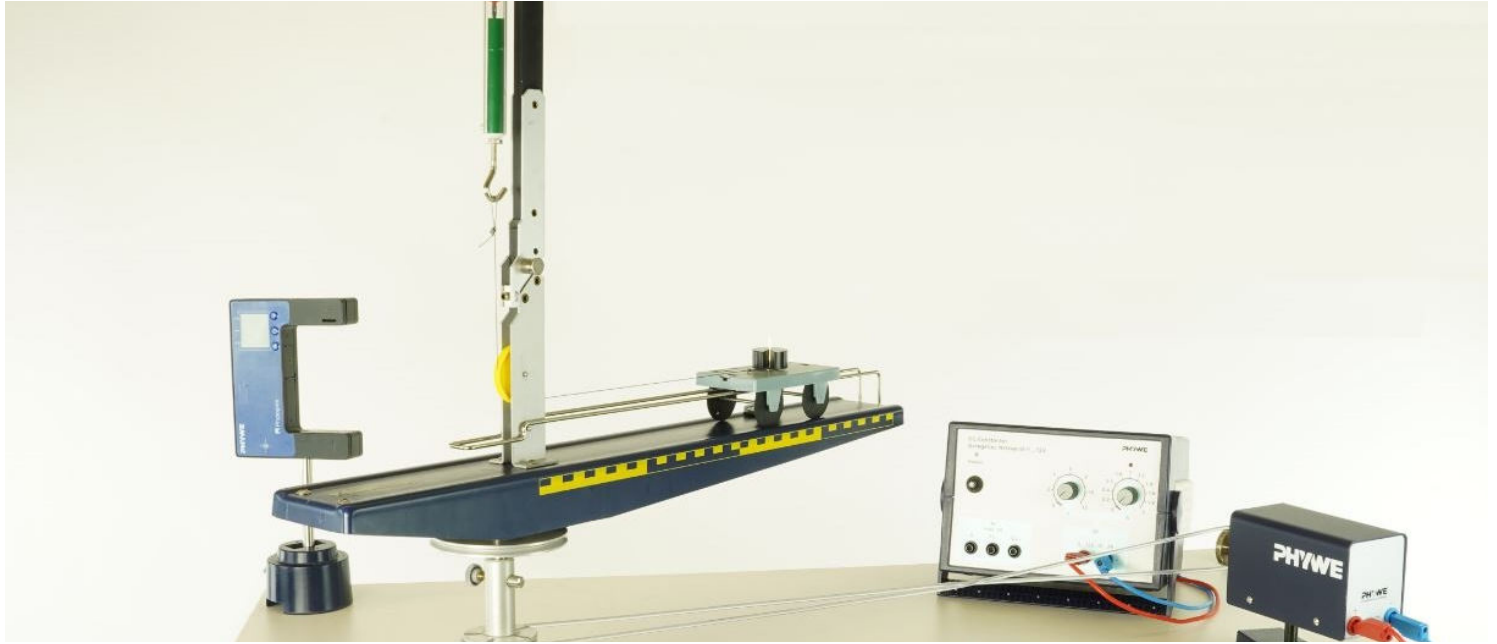


Centrifugal force



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:



<https://www.curriculab.de/c/606c1974e54a2f0003f6b31d>

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General information

Application

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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.

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.

Theory

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 ω is constant, and the car is at rest in the rotating reference system $\vec{U} = 0; \vec{v} = \text{const.} = 0; \vec{\omega} = 0$.

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

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

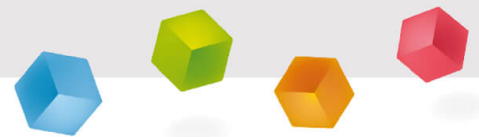
since $\vec{r} \perp \omega$, it follows that

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

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

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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.

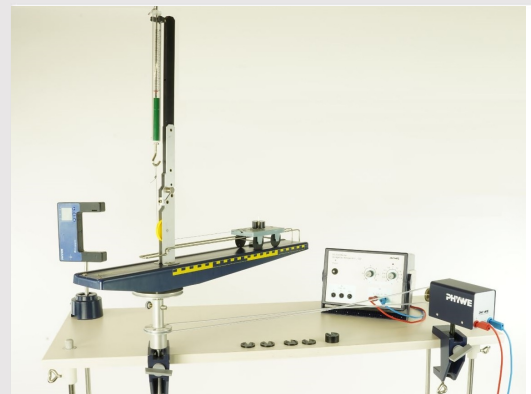


Fig. 1: Experimental set-up for the measurement of centrifugal force.

Procedure (1/3)

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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)

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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 .

$$\omega = 2\pi/T$$

Procedure (3/3)

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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.

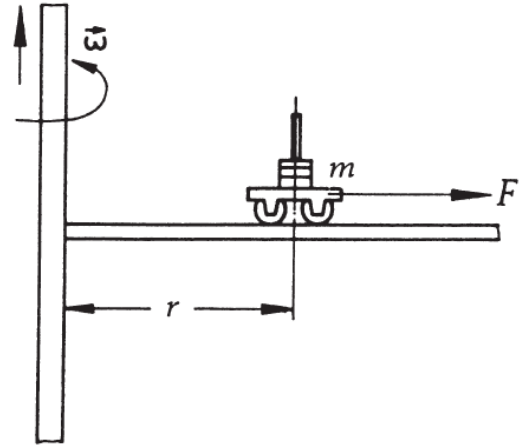
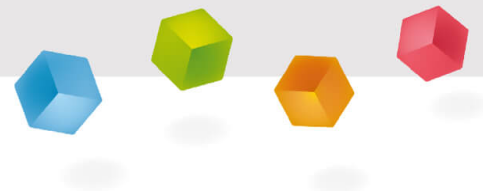


Fig. 2: Mass m , at rest in the rotating reference system.

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Evaluation



Evaluation (1/3)

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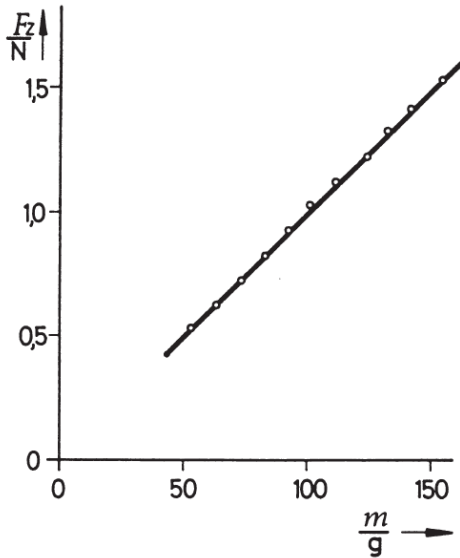


Fig. 3:
Centrifugal
force as a
function of the
mass m .

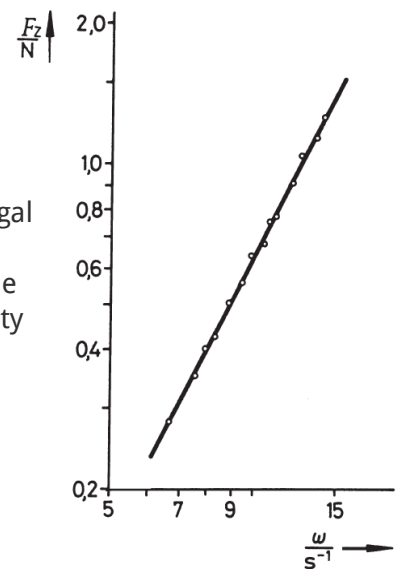


Fig. 4: Centrifugal
force as a
function of the
angular velocity
 ω .

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 :

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

Evaluation (3/3)

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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.

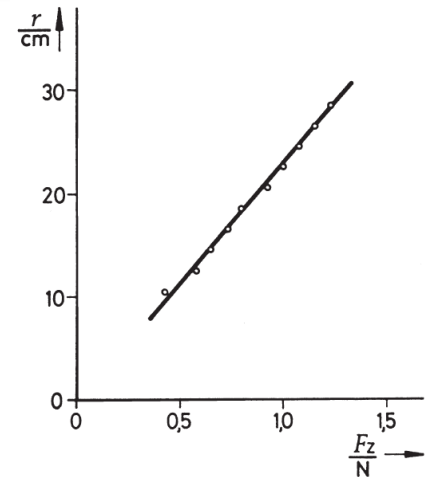


Fig. 5: Centrifugal force as a function of the radius.