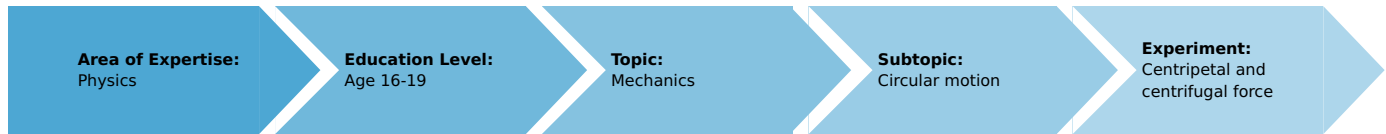


Centripetal and centrifugal force (Item No.: P6000660)

Curricular Relevance



Difficulty



Difficult

Preparation Time



10 Minutes

Execution Time



40 Minutes

Recommended Group Size



1 Student

Additional Requirements:

- PC
- software measureLAB

Experiment Variations:

Keywords:

centripetal force, centrifugal force, pseudo force, orbit, rotation, angular velocity

Introduction

In the everyday language use, the centrifugal force is often referred to as the cause of the occurring force during a uniform non-linear motion. Situated in a moving object that changes its direction, you can feel the centrifugal force pushing you to the outside as you can observe in a swing carousel. The actual circular motion is determined by the centripetal force.

The mass in motion as well as its radius and its angular velocity influence the centripetal force. In the experiment, the centripetal force is investigated by use of a force sensor that is situated close to the centre of rotation and connected to the mass by a fishing line that keeps it on its orbit.

Note:

The sign of the measured force depends on how the sensor is put into the setup. Therefore, all the measured values are seen as absolute values.

Task

1. Determination of the relation between centripetal force F and angular velocity ω .
2. Determination of the relation between centripetal force F and rotating mass m .
3. Determination of the relation between centripetal force F and the radius r of the circular movement.

Material


Position No.	Material	Order No.	Quantity
1	Cobra4 Wireless/USB-Link	12601-09	1
2	Cobra4 Sensor-Unit Force ± 10 N	12646-00	1
3	Support rod, stainless steel, $l = 250$ mm, $d = 10$ mm	02031-00	1
4	Right angle clamp PHYWE	02040-55	2
5	Fishing line, $d = 0,5$ mm, $l = 100$ m	02090-00	1
6	Cart for measurements and experiments	11060-00	1
7	Holding pin	03949-00	1
8	Weight, 150 g, for cart	11060-01	2
9	Slotted weight, 50 g, black	02206-01	2
10	Centrifugal force apparatus	11008-00	1
11	Driving belt	03981-00	1
12	Bearing unit	02845-00	1
13	Laboratory motor, 230 V AC	11030-93	1
14	Gearing 30/1, for laboratory motor	11029-00	1
15	Tripod base PHYWE	02002-55	1
16	Support base DEMO	02007-55	1
17	curricuLAB measureLAB	14580-61	1

Setup and implementation



Fig. 1: Setup of the experiment.

Part 1: Different angular velocities

- Set-up the experiment as shown in Fig. 1, but without the experimental motor. The Sensor-Unit Force 10 N has to be attached to the support rods in such a way that the hook with the attached fishing line is at the same height as the cart. The line should be parallel to the plane and run below the pulley without touching it.
- In the first experimental part, the additionally applied masses and the length of the fishing line can be chosen freely.
- Attach the Cobra4 Wireless/USB-Link with the Sensor-Unit Force and turn it on.
- Start the computer and connect it with the Wireless/USB-Link.
- Start the software package "measureLab" .
- Load the experiment "Centripetal force/Centrifugal force with Cobra4" (Phywe experiments > Physics > Age 16-19 > Mechanics > Circulat motion). All pre-settings required for a direct recording will be loaded.
- The sensor should show 0 in the digital display. If necessary, tare the sensor by opening the settings of the corresponding measurement channel and activating 0 (see fig. 2).

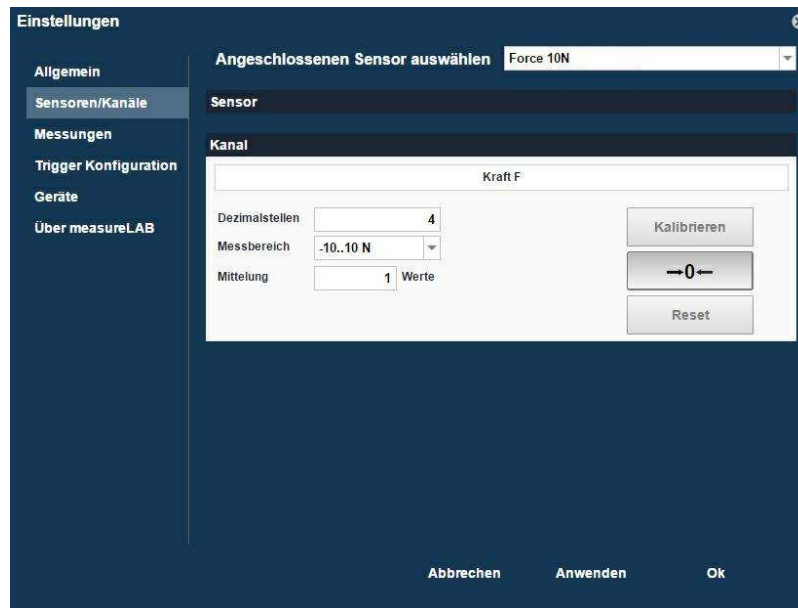






Fig. 2: Taring the Sensor.

- Manually rotate the centrifugal force apparatus in such a way that the measuring range of the sensor is not exceeded and start the recording of the measurement in „measureLab“ .
- After the centrifugal force apparatus has come to a stop, end the measurement. Save it  for further evaluation.

Part 2: Mass dependency

- To examine the dependency of the centripetal force on the mass of the moving object, the laboratory motor has to be coupled to the set-up as shown in Fig. 1. This way, the several measurements can be performed with the same angular velocity.
- After setting a proper angular velocity, it must not be changed during the consecutive measurements of this experimental part. Switch off the motor directly between two measurements without adjusting its rotational speed.
- Reload the experiment "Centripetal force/centrifugal force with Cobra4" in measureLab to have a clear display. If the sensor does not show 0, tare as above.
- Set the centrifugal force apparatus to rotate by the motor and start the recording in „measureLab“ , as soon as the displayed force remains roughly constant.
- Stop the measurement after about 20 s.
- Repeat the measurement with different cart weights and note the respective masses. Also regard the mass of the empty cart, not only the additional weights. To keep a better overview over the experiments, it might be advised to change the color of the linetype in the software for each measurement (select the paint mode in the diagram window before the next recording; make sure that old measurement files are not currently selected). Save the measurement for further evaluation .

Part 3: Radius dependency

Analogous to the investigation of the mass dependency, the dependency of the centripetal force on the radius of the circular motion can be examined as well. For this purpose, the angular velocity is kept constant again during the entire series of measurements by the use of the laboratory motor. The distance r between the centre of the cart and the rotational axis is modified by the use of different lengths of fishing line.

Results

Part 1:

Fig. 3 shows the course of the centripetal force after having pushed the centrifugal force apparatus until just before it comes to a stop. One can observe, that the force alternates around a mean values which is increasing in the course of the experiment. The oscillation occurs due to slightly tilted setups. The oscillation can be used to determine the current angular velocity for each period. If the oscillations are hard to recognise, the measurement should be repeated with a more tilted setup.

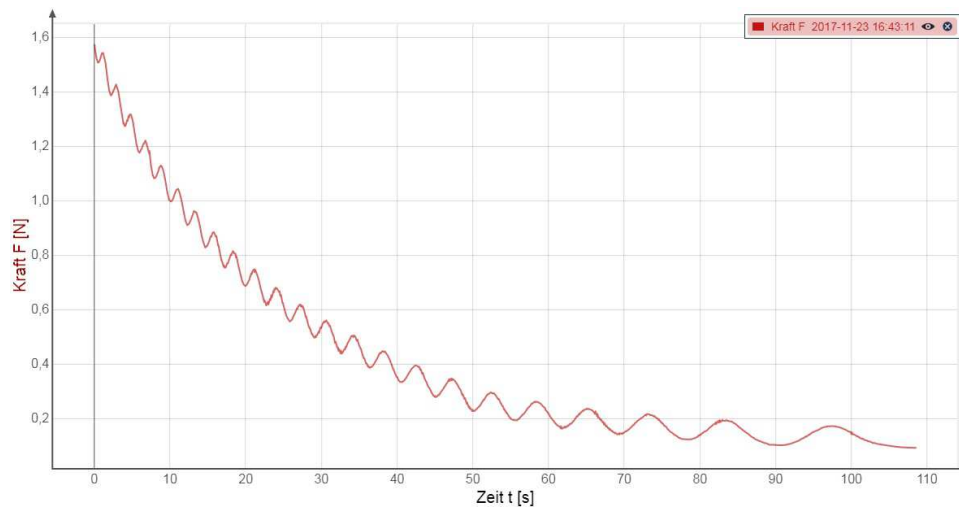


Fig. 3: Progress of the centripetal force for $m = 453$ g and $r = 30$ cm from the jolt of the apparatus until short before its stop.

Part 2:

Figure 4 shows the centripetal force F for the empty cart ($m = 53$ g) and with up to four additional weights in steps of 100 g, each. Except for slight periodic oscillations because of a not thorough horizontal alignment, the force remains constant during a measurement and increases for larger masses.

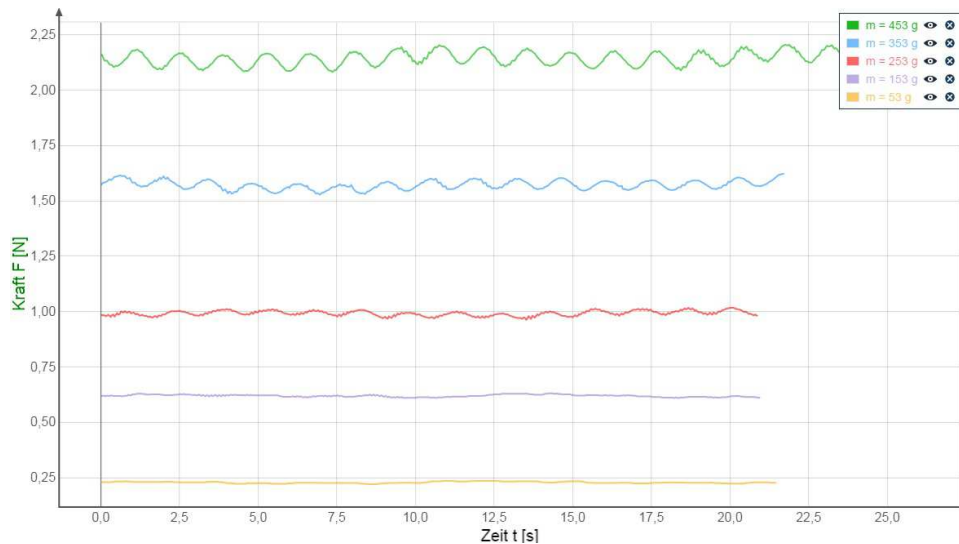


Fig. 4: Centripetal force in dependence of time for five different masses m at radius $r = 30$ cm.

Part 3:

The results for five different radii r are displayed in figure 5. The centripetal force F oscillates again, due to a non horizontal setup, periodically around a mean value. For bigger radii, the force increases.

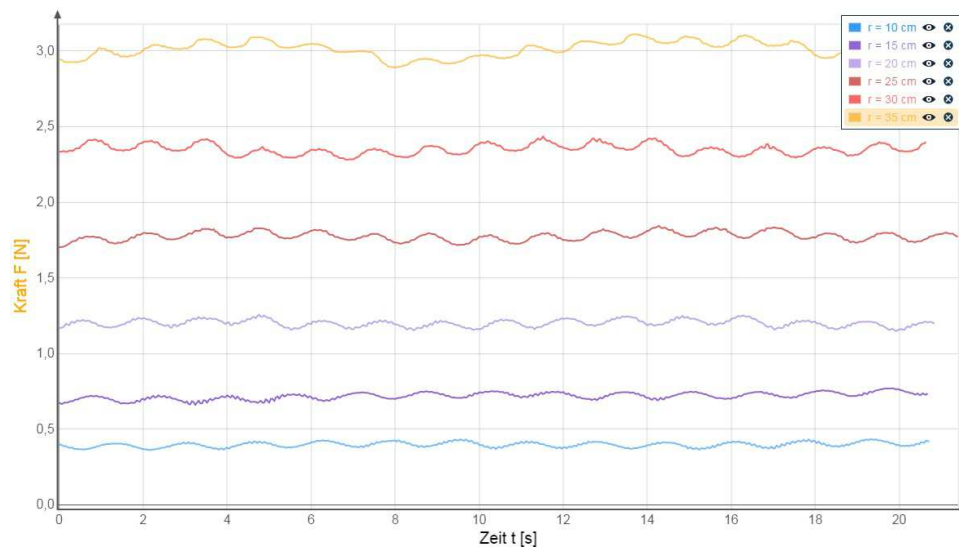


Figure 5: Centripetal force in dependence of time for different radii at constant mass $m = 453 \text{ g}$ and constant angular velocity.

Evaluation

Theory

A mass can move on a circular path because of the centripetal force F_r , which drives the moving object continuously to the centre of the orbit. The force acts parallel to the radial acceleration. Without the centripetal force, the object would move on a linear pathway following the velocity vector v .

The centripetal force fulfills the 2. law of Newton and, thereby, is a product of mass and acceleration. The acceleration in this case is called centripetal acceleration a_r , which depends on the radius r of the circular motion and its velocity v . Using force triangles, this dependency can be determined. One gets

$$F_r = m \cdot \frac{v^2}{r}.$$

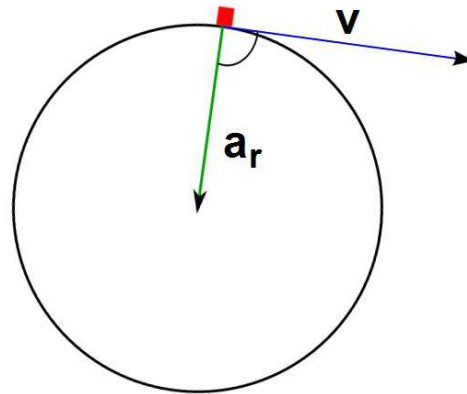


Fig. 6: Circular motion.

Introducing the angular velocity $\omega = v/r$, the centripetal force can be rewritten as

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

A body inside of the moving object would continue its motion on a linear path because of its inertia, but experiences the centrifugal force F_{Zf} because of the acceleration of the surrounding object. This force is only a pseudo force since it can only be measured in a floating frame of reference. It is not detectable for observations from the outside. From figure 6 it becomes obvious, that the centrifugal force shows in the opposite direction than the centripetal force but they have the same absolute value.

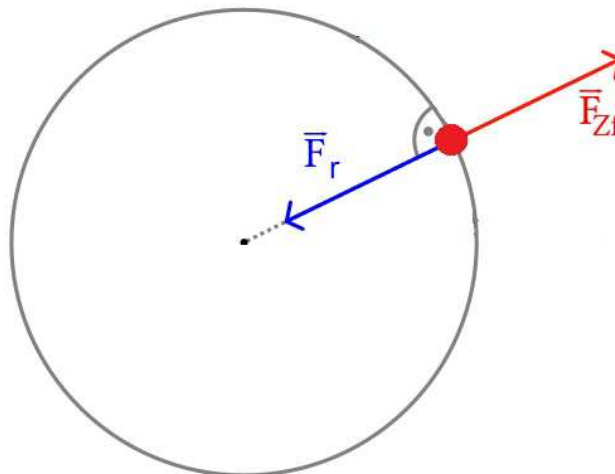





Fig. 7: Centripetal and centrifugal force.

Part 1:

Open the first measurement to determine the periodic time and the regarding mean force of the oscillation. At the beginning select the data pool  and create  a new file "periodic time" with unit [s]. Now click onto the new file and open a table .

Furthermore, create a data file for the corresponding mean centrifugal force "meanforce" in unit [N]. Open the file by dragging it into the table with the periodic time.

The data file of the measurement has to be open in a diagram. Then, the periodic time T of one oscillation can easily be determined with the measuring tool. Span the rectangle in such a way, that the vertical axis go right through two maxima (minima) in juxtaposition. The value for Δx in the display window equals the periodic time exactly. Take down the value in the table for the periodic time. The time slot can be neglected in this case, it will only show the measurement number.

Using the mean value tool over one period, one can determine the corresponding mean centrifugal force. Same as above, it is important that the start and end point of the measuring tool are exactly on two maxima (minima) next to each other. Make sure, that the channel of the force is selected and the mean force is taken down for the right periodic time. Therefore, it is advised to go through the periods and determine both the mean force and the periodic time right after each other. Take down the determined value directly next to the corresponding periodic time in the table of the mean centrifugal force.

Use the channel conversion tool, to calculate the square of the angular velocity (settings are displayed in figure 8). The formula is

$$\omega^2 = \frac{2\pi}{T}^2$$

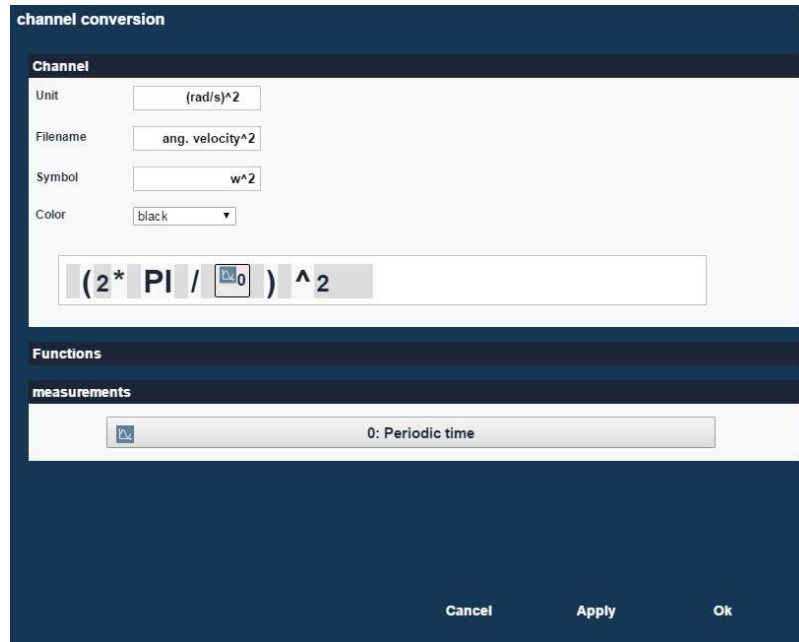


Fig. 8: Settings for channel conversion.

Now plot the mean values for the centripetal force against the squared angular velocity by creating a diagram with both data sets and then selecting the squared angular velocity for the x-axis (example fig. 9). The plot shows an approximately linear dependency. Hence, the centripetal force F is proportional to the squared angular velocity ω^2 , and for a constant radius r also proportional to the square of the orbital speed v .

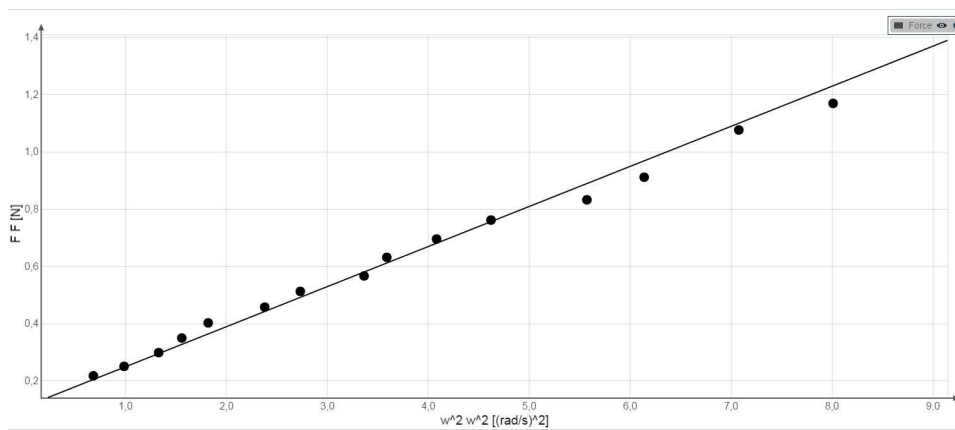


Fig. 9: Centripetal force depending on the square of the angular velocity.

Part 2:

Open the second part of the measurement. As described above create two new data files and open them in one table window. One channel is for the "mass m" in units of [g] and one is again for the "meanForce" in [N].

In the range showing the constant force—except for the periodic oscillations—a mean value of the force can be determined with the mean value tool as before. Take down the values in the table. In the same order like the mean forces, take down the corresponding mass in the "mass file". Then plot the mean values of the centripetal force F against the mass m by creating a diagram from both measurement files and selecting the mass on the x-axis. An example is given in figure 10. These data points

are on an approximate straight line, indicating that the centripetal force F is proportional to the mass m for a constant radius r and a non-varying angular velocity ω .

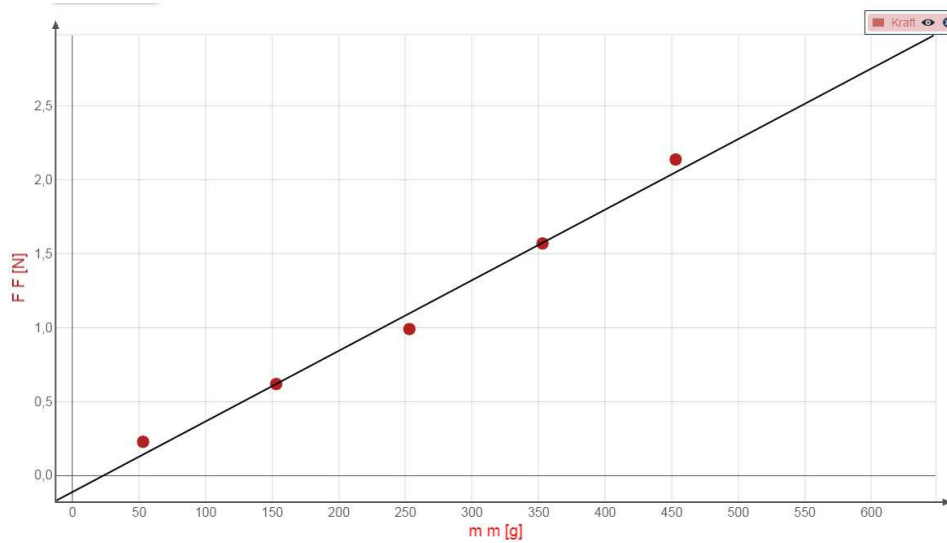


Fig. 10: Centripetal force F in dependence of mass m .

Part 3:

Similar to part 2, excerpt the mean values for the centripetal force and create a measurement data file where those values are inserted. An additional measurement data file now is needed for the different radii r . Then plot the mean values of the centripetal force F against the radius r by creating a diagram from both measurement files and selecting the radius on the x-axis. An example is given in figure 11. These data points also tend to be on a straight line, indicating that the centripetal force F is proportional to the radius r for a constant mass m and a non-varying angular velocity ω .

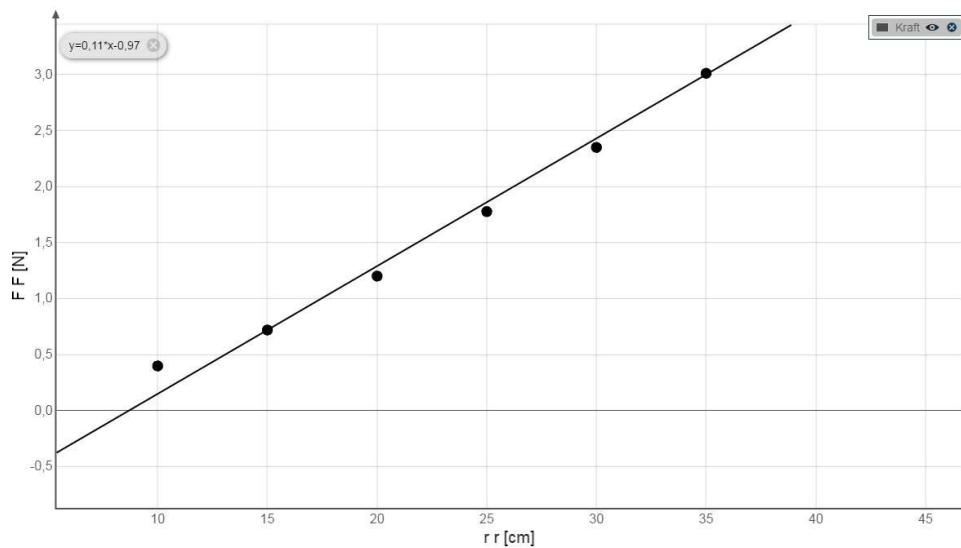


Fig. 11: Centripetal force F in dependence of the radius r .