Centrifugal force of an orbiting body - Measuring with the centrifugal force apparatus

Objects of the experiment

- Determination of the centrifugal force as function of the angular velocity for different radii.
- Determination of the centrifugal force as function of the angular velocity for two different masses.

Principles

According to Newton's law of inertia a body on which no force is acting is either at rest or moving in a straight line with constant velocity. If, therefore, a body executes a curvilinear motion – e.g. a circular motion – forces must act upon the body to produce the change of direction. These forces are well known from the cases of a vast vehicle which takes a curved path and the merry-go-around.

When measuring radial force (depending on the reference frame centripetal force or centrifugal force) the usual spring balances would alter because of their extension the radius of rotation of the body undergoing the measurement.
In this experiment, therefore, following a suggestion of Prof. Schürholz the measurement of the radial force is done with a torsion fiber with which the distance of the body from the axis remains the same at rest and at rotation. If the body is rotating in a circle the radial force tilts a mirror whereby the change in the arc radius caused by the tilt is negligible. The tilt of the mirror is proportional to the radial force and can be detected by a light pointer. The arrangement is calibrated using a precision dynamometer while the centrifugal force apparatus is idle.

The centrifugal or centripetal force F is given by

$$F = m \cdot \omega^2 \cdot r \qquad \text{(I)}$$

In this experiment F is determined as function of the angular velocity ω for two different radii r and two different masses m. The angular velocity is determined from the orbit period T of the light pointer. T is measured manually by a stop clock.

Apparatus

1 Centrifugal force apparatus	347 22
1 Experiment motor	347 35
1 Control unit for experiment motor	347 36
1 Lamp, 6 V/30 W	450 51
1 Lamp housing	450 60
1 Aspherical condenser	460 20
1 Transformer	521 210
1 Vertical scale, 1 m long	311 22
1 Stand base, V-shape, 20 cm	300 02
1 Stand rod, 47 cm	300 41
1 Saddle base	300 11
1 Leybold multiclamp	301 01
1 Stop clock	313 07
1 Precision dynamometer, 1.0 N	314 141

Setup

- Mount the experiment motor on the table like shown in Fig. 1.
- Insert the centrifugal force apparatus completely into the chuck. Thus an easy control of the zero position of light pointer is always possible during the experiment by just unfixing the centrifugal force apparatus and turn it to a position where the light pointer can be observed on the vertical scale.
- Position the vertical scale at a distance e.g. of about 80 cm from the experiment motor.
- Arrange the lamp with the aspherical condenser with a slit in the diaphragm holder in such a manner that on the vertical scale the light pointer becomes visible.

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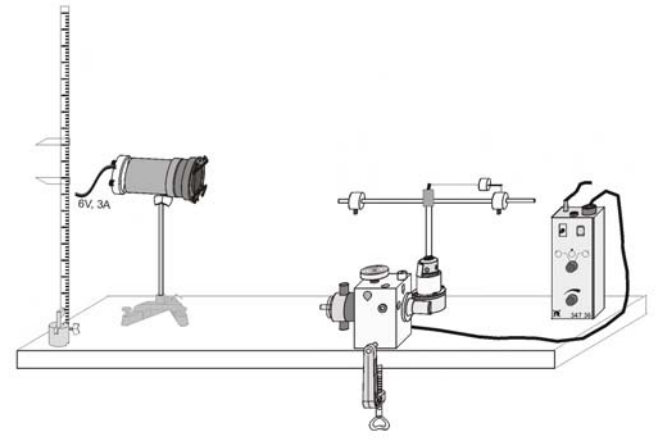

Fig. 1: Experimental setup (schematically).

Carrying out the experiment

The experiment can be performed in three steps.

a) Measuring the centrifugal force as function of the angular velocity for two different the radii

- Set up the centrifugal force apparatus for the mass m = 12,5 g with the wire r = 10 cm.
- Set the deflection of the light pointer to a small value, e.g. 2 cm, by increasing the speed of the experiment motor.
- Measure the period T with the stop clock. To increase accuracy measure the T as mean average of e.g. 10 periods.
- Repeat the these measurements for different speeds of the motor. It is recommended to increase the speed of the experiment motor each time in such a manner that the step of light pointer is increased by e.g. 2 cm.
- Repeat the experiment for the same mass with the wire r = 20 cm.

b) Measuring the centrifugal force as function of the angular velocity for two different the masses

- Set up the centrifugal force apparatus for the body of mass m = 25 g with the wire r = 10 cm.
- Set the deflection of the light pointer to a small value, e.g. 2 cm by increasing the speed of the experiment motor.
- Measure the period T with the stop clock. To increase accuracy measure the time for e.g. 10 periods.
- Repeat the these measurements for different speeds of the motor. It is recommended to increase the speed of the experiment motor each time in such a manner that the step of light pointer is increased by 2 cm.

***Hint:** For a comparison the experiment can be repeated also for the body with m = 25 g with r = 20 cm.*

c) Calibration of the centrifugal force apparatus

- Remove the body and the wire form the centrifugal apparatus.
- Set up the centrifugal force apparatus in such a manner that the light pointer can be observed on the vertical scale while the apparatus is at rest.
- Measure statically the deflection of the light pointer by using the precision dynamometer.

***Hint:** The zero point of the light pointer can easily be checked during and after the experiment by loosening the centrifugal force apparatus in the chuck.*

Measuring example

a) Measuring the centrifugal force as function of the angular velocity for two different the radii

Table 1: Deflection s of the light pointer and period T for two different radii r for the mass m = 12.5 g

$\frac{s}{cm}$	$\frac{T}{s}$ (r = 10 cm)	$\frac{T}{s}$ (r = 20 cm)
2	1.43	2.06
4	1.10	1.52
6	0.93	1.25
8	0.79	1.12
10	0.71	1.00
12	0.64	0.91
14	0.61	0.86
16	0.56	0.80
18	0.54	0.74
20	0.51	0.73
22	0.48	0.69
24	0.46	0.65
26	0.45	0.64
28	0.42	0.62
30	1.43	0.60

b) Measuring the centrifugal force as function of the angular velocity for two different the masses

Table 2: Deflection s of the light pointer and period T for two different masses m (r = 10 cm) – see Table 1.

$\frac{s}{cm}$	$\frac{T}{s}$ (m = 12,5 g)	$\frac{T}{s}$ (m = 25 g)
2	1.43	1.89
4	1.10	1.47
6	0.93	1.26
8	0.79	1.10
10	0.71	0.99
12	0.64	0.91
14	0.61	0.84
16	0.56	0.80
18	0.54	0.75
20	0.51	0.72
22	0.48	0.69
24	0.46	0.66
26	0.45	0.63
28	0.42	0.61
30	1.43	0.60

c) Calibration of the centrifugal force apparatus

Table 3: Force F as function of the deflection s of the light pointer

$\frac{F}{N}$	$\frac{s}{cm}$
0.0	0.0
0.1	2.0
0.2	5.0
0.3	7.5
0.4	10.0
0.5	13.0
0.6	15.0
0.7	17.5
0.8	20.5
0.9	22.5
1.0	25.0

Evaluation and results

Fig 2. shows that the deflection s of the light pointer is proportional to the force F acting on the mirror:

$$F \sim s \quad \text{(II)}$$

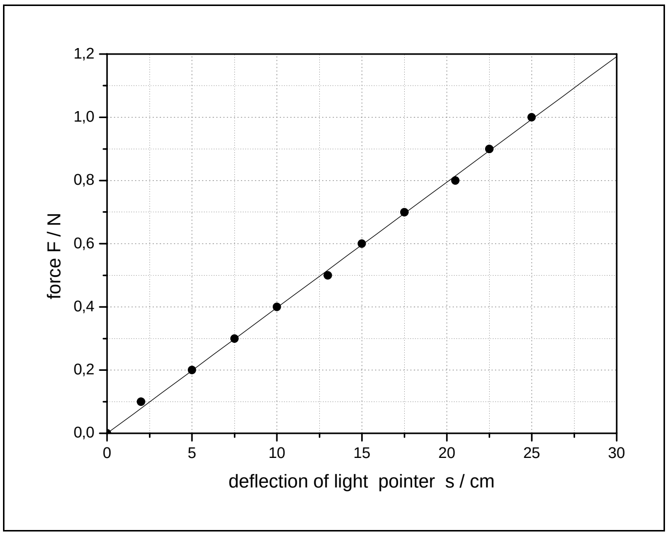

Fig. 2: Measured force F as function of the deflection s of the light pointer (centrifugal apparatus at rest).

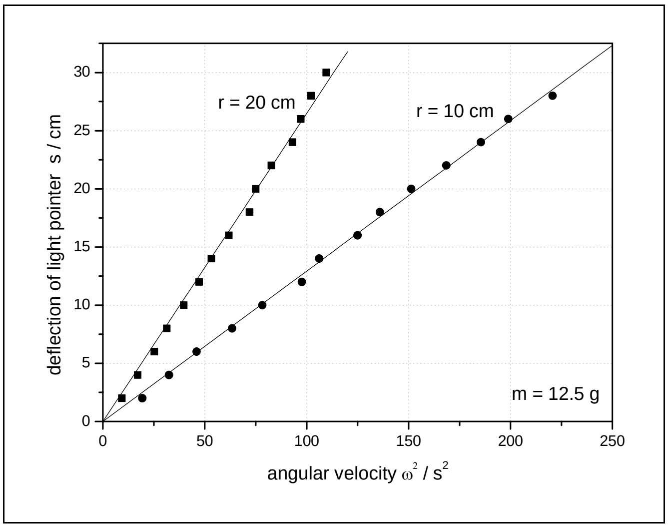

Fig. 3: Measured the deflection s of the light pointer as function of the square of the angular velocity for m = 12.5 g.

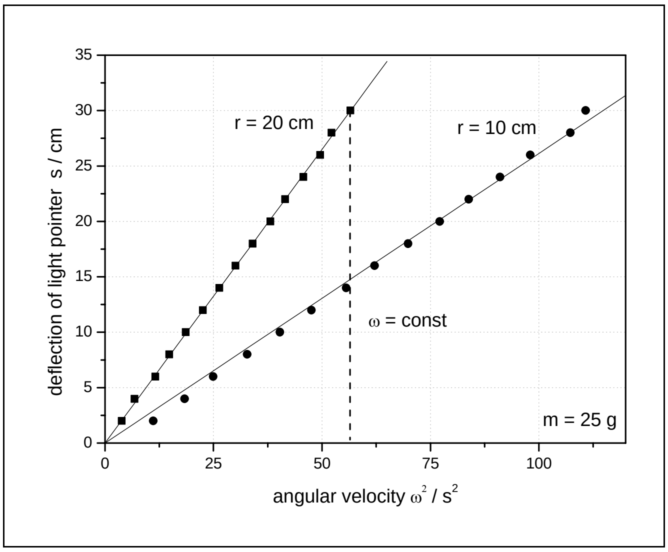

Fig. 4: Measured the deflection s of the light pointer as function of the square of the angular velocity ω for m = 25 g.

Fig. 3 to Fig. 5 show also that the centrifugal force F is proportional to the square of angular velocity ω:

$$F \sim \omega^2 \qquad \text{(III)}$$

Fig. 3 and Fig. 4 shows that the centrifugal force F is proportional to the radius r. For a constant angular velocity ω the force F increases in proportion to the radius:

$$F \sim r \qquad \text{(IV)}$$

Fig. 5 shows that the centrifugal force F is proportional to the mass m of the body in the centrifugal force apparatus. For a constant angular velocity ω the force F increases in proportion to the mass:

$$F \sim m \qquad \text{(V)}$$

Collecting together the results of equation (III), (IV) and (V) gives equation (I).

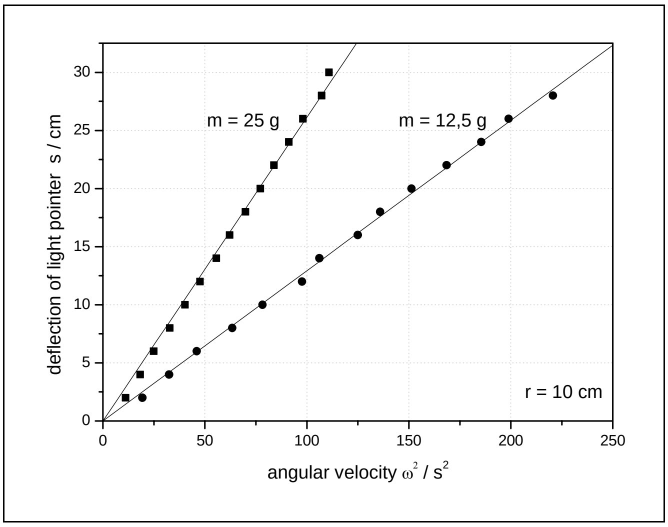

Fig. 5: Measured the deflection s of the light pointer as function of the square of the angular velocity ω for r = 10 cm.

Supplementary information

From a stationary observer the body must be drawn with the radial force towards the axis of rotation. Instead of flying off in a straight line along the tangent the body has been forced to travel along a circular path due to the radial force (centripetal force).

The experiment are interpreted differently for an observer who rotates with the body. This observer concludes that a force acts on the body in order to keep it in its place. This centrifugal force is equal and opposite to the centripetal force.

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