Centrifugal force on an orbiting body

Measuring with the central force apparatus

Objects of the experiments

- Measuring the centrifugal force F on an orbiting body as a function of the angular speed ω.
- Measuring the centrifugal force F as a function of the path radius r.
- Measuring the centrifugal force F as a function of the mass m.

Principles

The centrifugal force acting on an orbiting body is

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

where m is the mass of the body, ω its angular speed and r the radius of the orbit. In the central force apparatus, the centrifugal force on a test body is transmitted via an angled lever and a toe bearing to a leaf spring with strain gauge. The transmission ratio of the lever system is chosen so that changes in the path radius r of the orbiting body are negligible. The force acting on the strain gauge is measured by means of a newtonmeter. The analogue output signal of the newtonmeter is connected to the Y input of an XY recorder. A tachymeter connected to the central force apparatus measures the angular speed and supplies an analogue signal, which is fed to the X input of the recorder.

At a constant path radius r and a constant mass m, the parabolic shape of the curve recorded confirms the proportionality

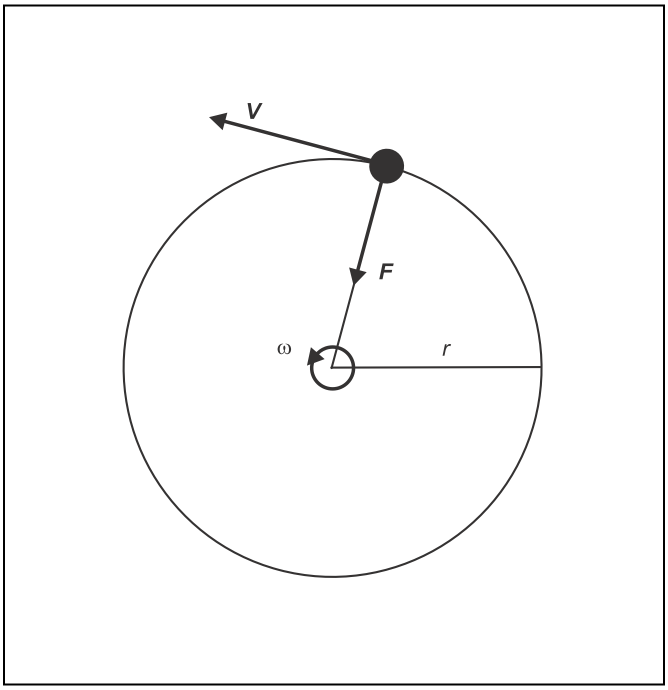
$$F \propto \omega^2 \quad \text{(II)}.$$

Measurements at different path radii r and with different masses m confirm the proportionalities

$$F \propto r \quad \text{(III)}$$

and

$$F \propto m \quad \text{(IV)}.$$



The centrifugal force F on an orbiting body

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Apparatus

1 central force apparatus	347 21
1 tachymeter	337 41
1 newtonmeter	314 251
1 multicore cable, 6-pole, 1.5 m long	501 16
1 variable extra low voltage transformer S	521 35
1 XY-Yt-recorder	575 662
1 bench clamp	301 06
Connection leads	

Safety notes

As the central force apparatus rotates at a high speed, carrying out this experiment requires particular care.

- Stand well back, and never reach into the rotating apparatus.
- See to it that the central force unit is well fixed with the bench clamp.
- Position other devices at a sufficient distance from the central force apparatus.

Setup

The newtonmeter must warm up for at least 15 minutes before the experiment starts:
Swith on the newtonmeter with the central force apparatus connected.

The experimental setup is illustrated in Fig. 1.

– Fix the central force unit in the bench clamp, and connect it to the newtonmeter via the multicore cable; connect the analogue output of the newtonmeter to the Y input of the recorder (y-axis: 1 V/cm), and switch the newtonmeter on.
– Connect the drive motor **(a)** to the low-voltage power supply paying attention to the polarity.
– Screw the holding clamp of the tachymeter **(b)** into the tapped hole of the central force apparatus.
– Mount the motion sensor **(c)**, and see to it that the contact between its running wheel and the O-ring of the central force unit is perfect.
– Connect the measuring unit **(d)**, and feed its output to the X input of the recorder (x-axis: 0.1 V/cm).

The central force apparatus is driven by the O-ring at the radius r = 10 cm. The transmission ratio between the rotational speeds of the tachymeter and the central force unit is 4 : 1. Therefore, the angular speed ω of the central force apparatus is 25 s^{-1} when the tachymeter displays the orbital velocity v = 1 m s^{-1}.

Carrying out the experiment

a) The centrifugal force F as a function of the angular speed ω:

– Make the zero compensation by setting the pushbutton COMPENSATION of the newtonmeter to SET.
– Fix the mass m = 100 g at the distance r = 25 cm from the axis of rotation.
– Switch the recorder on, and lower the recording stylus.
– Set the output voltage of the low voltage power supply to zero, and switch the low voltage power supply on.
– Slowly increasing the output voltage, record the measurement curve.
– Lift the recording stylus, and set the output voltage back to zero.
– Vary the radius r, for example, and record other measurement curves. Afterwards switch the recorder off.

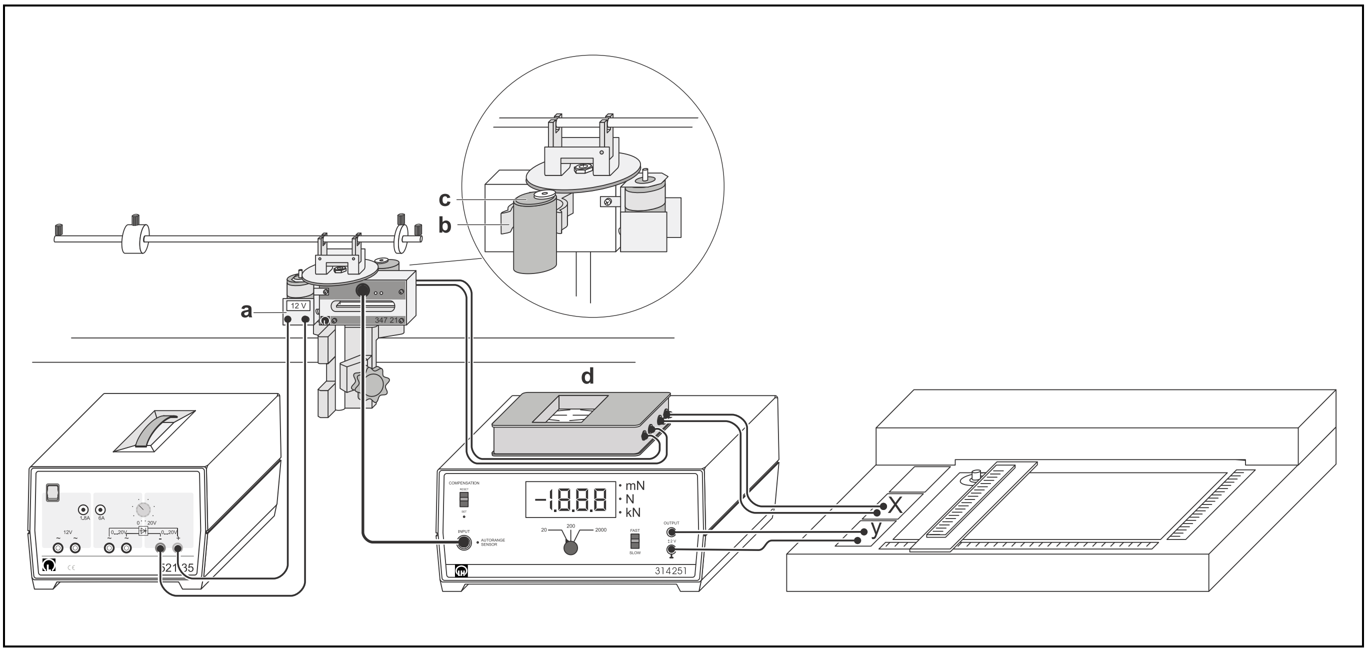


Fig. 1 Experimental setup for measuring the centrifugal force F on an orbiting body

b) The centrifugal force *F* as a function of the radius *r*:

– Repeat the zero compensation of the newtonmeter.
– Fix the mass m = 50 g at the distance r = 25 cm from the axis of rotation.
– Increase the output voltage until the tachymeter displays v = 0.6 m s^{-1} (that is ω = 15 s^{-1}).
– Measure the force F, and take it down.
– Decrease the distance r in steps 5 cm down to 5 cm. Each time adjust the same angular speed, and repeat the measurement.

c) The centrifugal force *F* as a function of the mass *m*:

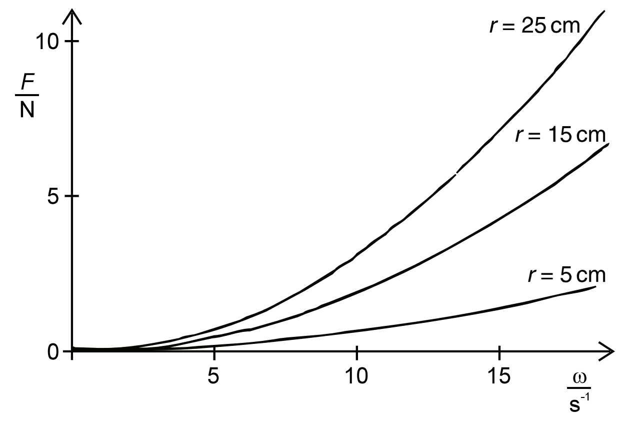
– Repeat the zero compensation of the newtonmeter.
– Fix the mass m = 50 g at the distance r = 15 cm from the axis of rotation.
– Increase the output voltage until the tachymeter displays v = 0.6 m s^{-1} (that is ω = 15 s^{-1}).
– Measure the force F, and take it down.
– Mount the masses 75 g and 100 g, adjust the same angular speed in each case and repeat the measurement.

Measuring example and evaluation

a) The centrifugal force *F* as a function of the angular speed ω:

Fig. 2 shows the measurement curves recorded with the recorder. The parabolic shape of the curves confirms the proportionality $F \propto \omega^2$.

Fig. 2 The centrifugal force F as a function of the angular speed ω (m = 100 g) constant



b) The centrifugal force *F* as a function of the radius *r*:

Table 1: The centrifugal force as a function of the radius r (m = 50 g, ω = 15 s^{-1})

$\frac{r}{\text{cm}}$	$\frac{F}{\text{N}}$
5	0.6
10	1.4
15	2.2
20	2.9
25	3.7

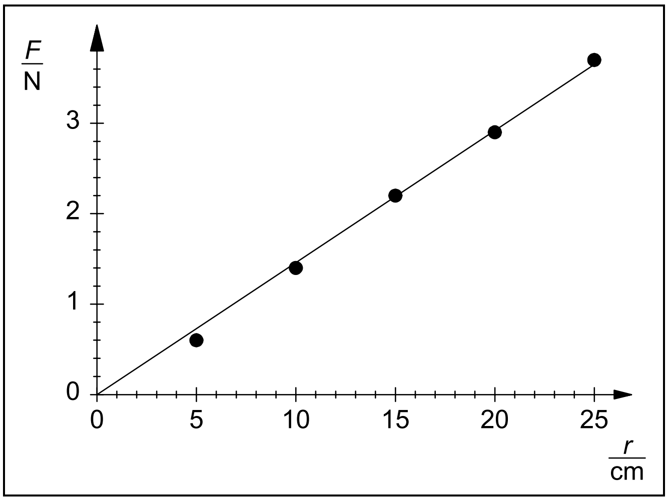


Fig. 3 The centrifugal force F as a function of the radius r (m = 50 g, ω = 15 s^{-1})

Fig. 3 is a plot of the measuring values from Table 1. Within the accuracy of measurement, they agree with the straight line drawn through the origin, that is, $F \propto r$.

c) The centrifugal force *F* as a function of the mass *m*:

Table 2: The centrifugal force as a function of the mass m (r = 15 cm, ω = 15 s^{-1})

$\frac{m}{g}$	$\frac{F}{N}$
50	2.2
75	3.2
100	4.4

Fig. 3 is a plot of the measuring values from Table 2. The agreement with the straight line drawn through the origin confirms the proportionality $F \propto m$.

Fig. 4 The centrifugal force F as a function of the mass m (r = 15 cm, ω = 15 s^{-1})