

Related topics

Centripetal force, rotary motion, angular velocity, apparent force, use of an interface.

Principle and task

As an object moves on a circular path with a certain angular velocity ω , it is constantly accelerated towards the centre of the path. This centripetal acceleration a_z is the result of central force F_z . This is proportional to the square of the angular velocity ω^2 , the radius r of the circular path and the mass m of the object.

Equipment

Centrifugal force apparatus	11008.00	1
Car	11060.00	1
Slotted weight, 50 g, black	02206.01	3
Slotted weight, 10 g, silver bronze	02205.02	4
Bearing unit	02845.00	1
Driving belt	03981.00	1
Holding pin	03949.00	1
Laboratory motor, 220 V AC	11030.93	1
Gearing 10/1, for 11030.93	11028.00	1
COBRA-interface 2	12100.93	1

PC COBRA data cable RS 232, 2 m	12100.01	1
Measuring module Newton	12110.00	1
Newton sensor	12110.01	1
Softw. COBRA Force (Win)	14290.61	1
Basic Softw. f. PHYWE Windows prog.	14099.61	1
Bench clamp -PASS-	02010.00	3
Right angle clamp -PASS-	02040.55	2
Support rod -PASS-, square, l 250 mm	02025.55	1
Support rod -PASS-, square, l 400 mm	02026.55	1
Fish line, l 100m	02090.00	1
Measuring tape, l = 2 m	09936.00	1

The PHYWE WINDOWS® Basic Software (14099.61) must be installed on the computer being used in order to run the software.

Problems

- 1) Measurement of the force as a function of time.
- 2) Measurement of the central force as a function of angular velocity ω and ω^2 .
- 3) Measurement of the central force as a function of the mass.
- 4) Measurement of the central force as a function of the radius.

Fig.1: Experimental set-up: Dependence of central force on angular velocity, track radius and mass with PC interface.



Set-up

- As shown in Fig. 1. Plug the force measuring module into the MODUL 1 input of the interface. When using the program Zentral_COM1 or Zentral_COM2, tie the fishing line to the end of the measuring car facing the rotational axis, threading it beneath the deflection pulley and through the eye. Attach the line to the decoupling hook and, finally, attached to the hook on the force meter from the other side of the decoupling hook. Make sure that the movable axis of the force meter, the fishing line and the eye are lined up horizontally.

Procedure

Measuring central force and rotation time:

- First determine the mass of the measuring car and any weights to be placed on it. You can use the program DIGIT_COM1 or DIGIT_COM2 for this (See the experiment “The force meter as a laboratory balance” for a description of the program).
- Next, start the program F(t)_COM1 or F(t)_COM2 (See the experiment “Determination of surface tension by the pull-out method” for a description of the program).

Turn the motor on to begin rotation of the centrifugal force apparatus: the periodic fluctuation of force as a function of time is displayed (see Fig. 2). There is a pumping motion at the force probe, and the eye on the centrifugal force apparatus also moves back and forth slightly when the apparatus is viewed from the side. This eccentricity is intentional,

it allows the rotational velocity to be determined. Now, you can count the oscillations lying between two vertical time markings on the graph and calculate the period from this. Increasing the <Average> (e.g. 100) averages the force causing the amplitude of the oscillation to decrease. The average of force corresponds to the central force.

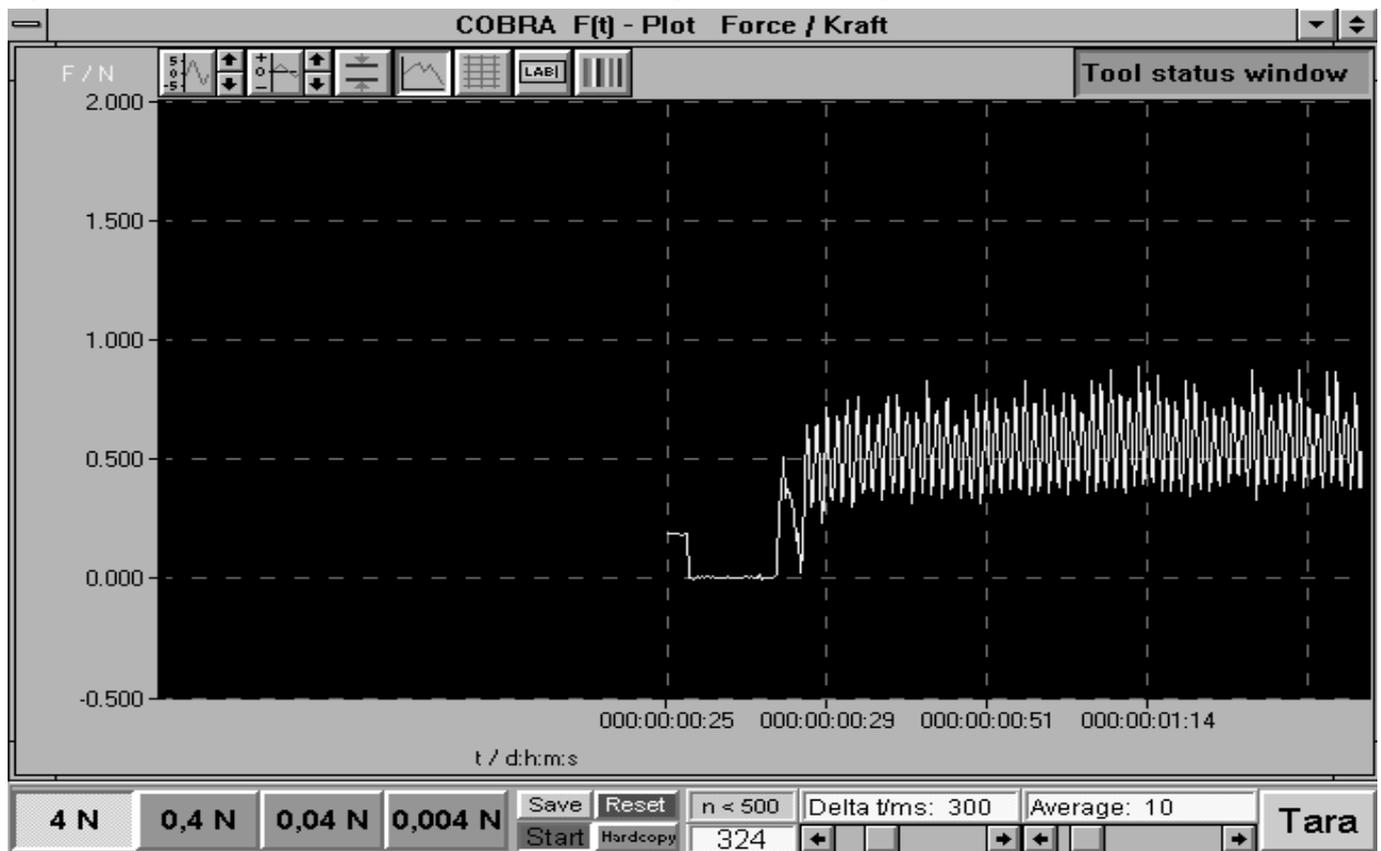
- COBRA: Depending on whether COBRA is connected to COM1 or COM2 of the computer, double-click on the icon to start either the Zentral_COM1 or Zentral_COM2 program, which were specially developed for the centrifugal force apparatus, to measure the central force and the period simultaneously.

The centrifugal force apparatus is standing still to start.

As soon as the program is loaded, the system performs a tare, this takes about 5 seconds. The force meter must not be moved or jarred during taring. After incorrect taring, you can restart taring by pressing the <Tara> button once the yellow highlighting has gone out. If you are using a slow computer, the set sample times should be greater than 300 ms. With very slow computers and a set sample time of 300 ms, the yellow highlighted “Tara!” button stays lit a long time, and taring is incorrect.

You can set the sample rate by adjusting the scroll bar <Delta t/ms>. Each connected computer has its own maximum sample rate. If the sample rate is too high, there are data communications errors, evidenced by apparent measuring errors. After correct taring, the force displayed in the upper left should be about 0.00 N.

Fig. 2: Sinusoidal curve of force as a function of time. <Average> should not be greater than 10.



Notes

The sample time $\langle \Delta t / \text{ms} \rangle$ determines the precision of the constant period reading. Generally, you should set a sample time that is as short as possible while ensuring problem-free data communications with the interface. Determine this time by trial and error. The preset value of 300 ms is based on a 486 PC with 66 MHz.

— Central force as a function of angular velocity

Enter the mass of the car and any weights placed on it in the field “m...kg” and enter the distance of the centre of the car to the rotational axis in the field “r...m”. Press “Return” on the keyboard after each entry.

Turn the motor on to begin slow rotation of the centrifugal force apparatus ($T \approx 2$ s). The values for force and the rotation time (blue digital display, upper left) stabilise after about 15 s. Click on the $\langle \text{Enter} \rangle$ button (bottom right on the screen) to save the values in the computer’s memory. While it is saving, the measurements are also displayed in a graph.

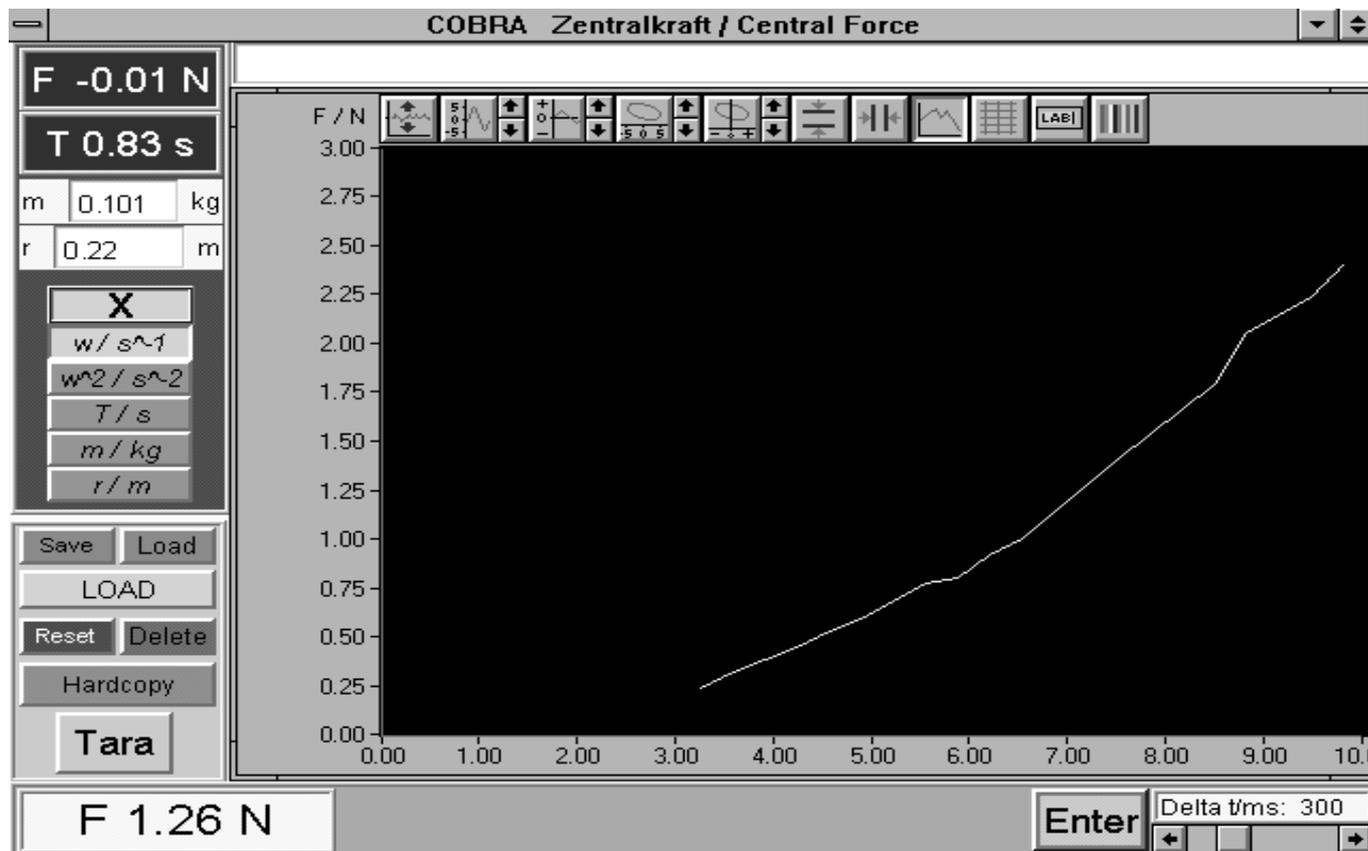
You can alter the physical variable of the x-axis by clicking on the blue-green buttons (on the left) $\langle w / 1/s; w^2 / 1/s^2; T / s; m / kg; r / m \rangle$. They-axis always indicates force F / N . After changing the variable for the x-axis (by clicking on the appropriate button), the scaling remains the same as the previously displayed graphic. To initiate automatic rescaling, click on the left button in the upper left of the graph. The other buttons (from left to right) are for the following functions:

autoscale; scale y-axis; shift y-axis; scale x-axis; shift x-axis; horizontal cursor lines; vertical cursor lines; connect points with lines; grid, coordinate cross, no grid; label axes; select colour for graph.

If you press the $\langle \text{Enter} \rangle$ button by mistake, you can delete the last measurements points taken by clicking on the $\langle \text{Delete} \rangle$ button.

Gradually increase the rotational velocity step by step and add the new measurements to the graph by clicking on $\langle \text{Enter} \rangle$. The yellow digital display at the lower left shows the theoretical central force based on the values entered for the car mass, radial distance from the rotational axis and the current measured angular velocity. This can be continuously compared to the current force displayed in the upper left of the screen. Usually, the measured force is slightly greater than the theoretically calculated one. This is due to frictional loss at the deflection pulley and eye as well as the weight of the decoupling hook. If the variables “ $w^2 / 1/s^2; m / kg; r / m$ ” are selected for the x-axis, the button $\langle y=mx+b \rangle$ appears at the bottom of the screen when enough measurements have been taken. Pressing on this button displays a linear regression through the current measurement values (you may also need to click on the autoscale button). The slope m of the regression line and the y-axis section b are indicated. The slope m has different physical meanings depending on the x-axis selected. This is indicated directly to the left of the $\langle y=mx+b \rangle$ button. Furthermore, the calculated value based on the values entered for m and r and the currently measured angular velocity ω is displayed here.

Fig. 3: Central force F as a function of angular velocity ω .



— Central force as a function of track radius

Measurement and evaluation for this section are basically the same as for the previous section. Now, however, the measurement points are not based on the angular velocity ω , they are a reflection of the distance of the rotational axis to the middle of the measuring car. Set the motor to a constant rotational velocity and measure the central force. Next, turn the motor off without changing the rotational speed setting. Vary the distance of the rotational axis to the middle of the measuring car by lengthening or shortening the fishing line.

Measure the new distance with the measuring tape and enter the value in the appropriate field (r...m). Turn the motor back on and accept the new measurement after approx. 20 s by clicking on <Enter>. If the angular velocity is different from that of the previous measurement point, carefully readjust the rotational velocity on the motor slightly.

— Central force as a function of mass

Measurement and evaluation is basically the same as described above. Now, however, vary the mass of the car and enter in the field "m...kg".

Results

— Figures 3 and 4 show examples of the central force F_z measured for the various rotational velocities. The angular velocity ω is calculated from the period T as follows:

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

— A (punctiform) object moving uniformly on a circular path constantly changes the direction of its speed, since the velocity vector is always directed tangentially to the circular path. An object with a mass m moving on a circular path with radius r and with an angular velocity ω is accelerated at each moment towards the centre of the circle by the figure

$$a_z = -a_r = r \cdot \omega^2$$

(centripetal acceleration). According to Newton's Basic Law of Dynamics, a force directed towards the centre of the circle must act upon the body, the centripetal force:

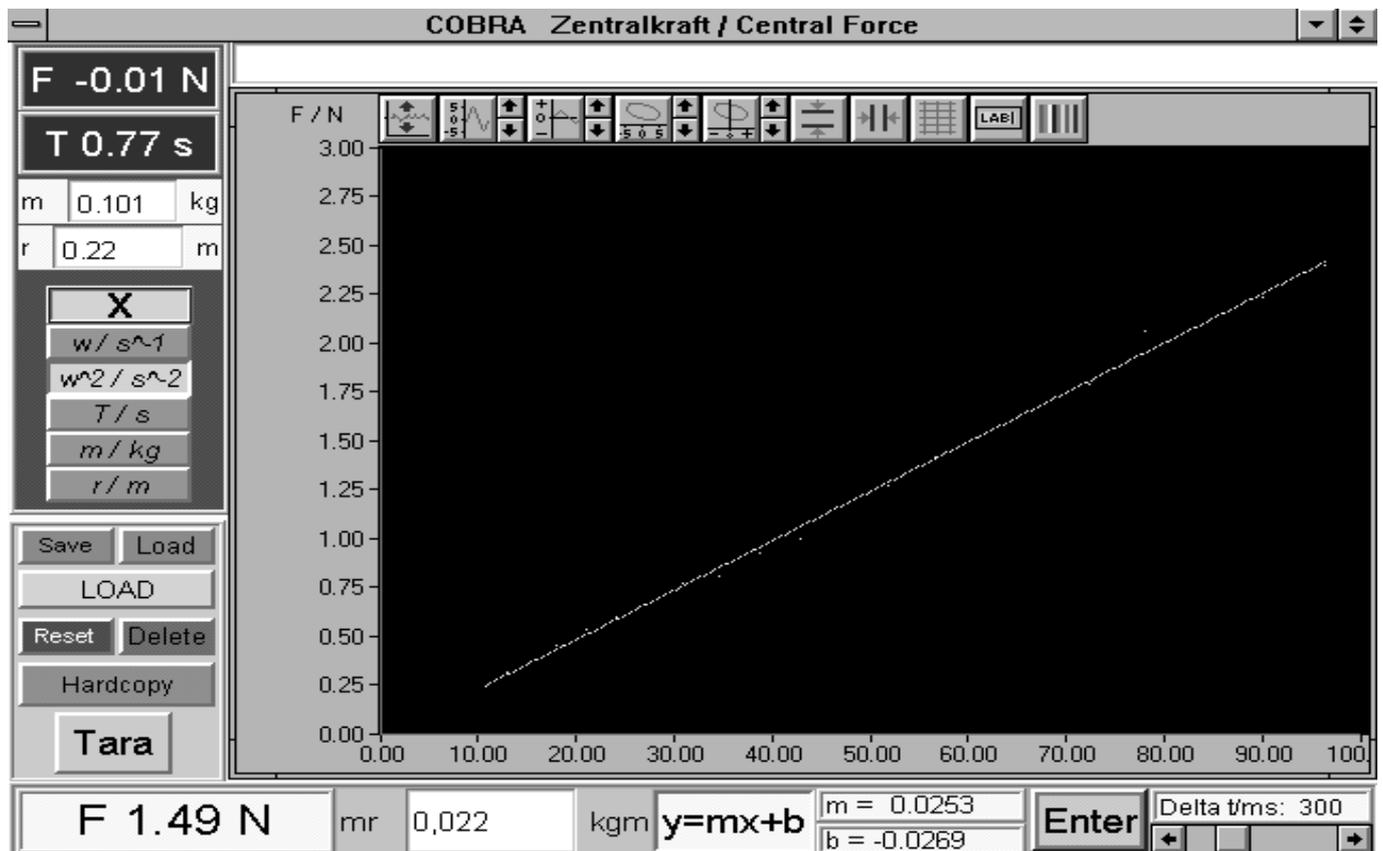
$$F_z = m \cdot a_z = m \cdot r \cdot \omega^2$$

— The slope m of the regression line displayed in Fig. 4 is used to derive the proportionality factor $m \cdot r = 0.0253 \text{ kgm}$. With the previously entered values for mass m and the radius r , the calculated proportionality factor $m \cdot r$ is displayed to the left of the button <y=mx+b>. This value is adjusted depending on the selected variable for the x-axis.

— Figure 5 is an example of a measurement for the relation between central force F_z and mass m with a constant track radius and constant angular velocity.

The resulting line has a slope corresponding to the product $r \cdot \omega^2$. The slope of the regression line is displayed to the right of the <y=mx+b> button and the theoretical value $r \cdot \omega^2$ to the left.

Fig. 4: Central force F as a function of the square of angular velocity ω^2 .



- Figure 6 shows central force F_z as a factor of the track radius r , with constant mass m and constant angular velocity. The resulting line has a slope corresponding to the product $m \cdot \omega^2$. The slope of the regression line is displayed to the right of the $\langle y=mx+b \rangle$ button and the theoretical value $m \cdot \omega^2$ to the left.

Notes

- $\langle \text{Reset} \rangle$ deletes all previously recorded measurement values. You should click on this button before starting a new series of measurements.
- $\langle \text{Delete} \rangle$ only deletes the last recorded measurement value, i.e. one measurement point is deleted from the graph each time you click on this button.
- Click on $\langle \text{Save} \rangle$ to save the current series of measurements on the hard drive or on a floppy disk. The measurement values are stored in the form of a table with the columns separated by a "Tab" so that these values can easily be used in spread sheet programs. The columns are as follows: F in N; ω in s^{-1} ; ω in s^{-2} ; T in s; m in kg; r in m.
- $\langle \text{Load} \rangle$ loads a previously saved series of measurements onto the computer, allowing it to be viewed and evaluated through linear regression.
- To display a loaded measurement curve, click on the $\langle \text{LOAD} \rangle$ button below the $\langle \text{Save} \rangle$ and $\langle \text{Load} \rangle$ buttons. You can compare the loaded measurements with the currently recorded measurements by consecutively clicking on the $\langle \text{LOAD} \rangle$ button.

- Clicking on the $\langle \text{Hardcopy} \rangle$ prints out the entire display on screen on the connected printer.
To save on ink or toner, it is recommended to set the background of the graphic (Scope) to white and the line colour (Data) to black by clicking on the colour selection button for the graphic, located on the right end on the control button bar.
- The measured force is usually somewhat (approx. 0.05 N) larger than the theoretically expected force. This effect is due to frictional losses at the pulley, the eye and the wheels of the measuring car as well as the mass of the decoupling hook.

Fig. 5: Central force F as a function of mass m .

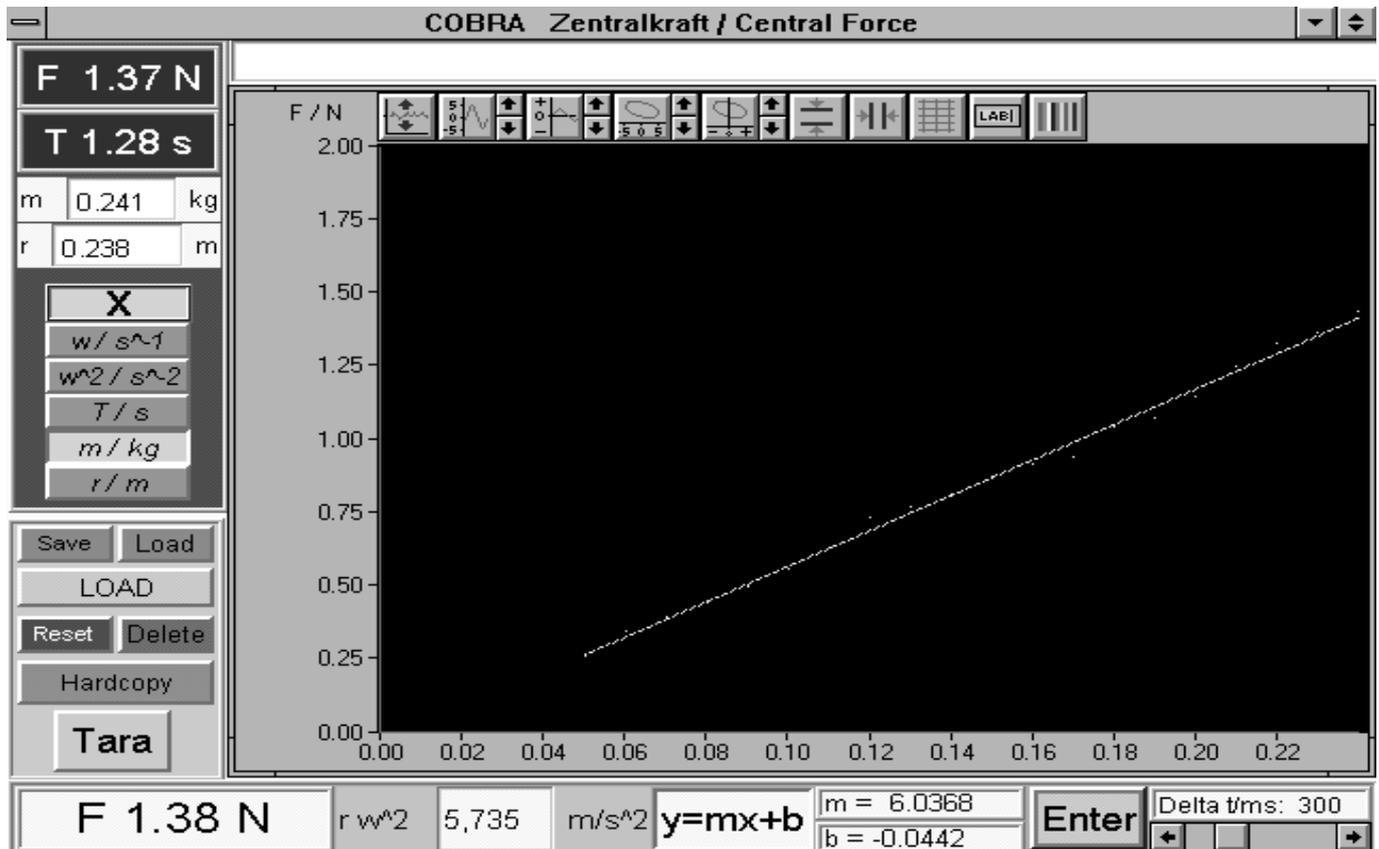


Fig. 6: Central force F as a function of radius r .

