How is Change in Motion Connected to Acting Force?

In order to set an object in motion (or change the state of motion in general), we need a force acting on the object. What do we measure if we hang a weight on a dynamometer, and we move the dynamometer up and down a) quickly or slowly, b) in water or in the air?

What you need:

- Vernier DFS-BTA dynamometer
- an empty tube of fizzing tablets (e.g. Berocca)
- pebbles, screws or other weights you can put into the tube
- a string
- a ruler
- a graduated cylinder high enough, so that you can fit the tube of fizzing tablets into it

Tasks:

Estimation of measurement results

Before conducting the measurement, read the procedure and estimate the results. Try to sketch on a piece of paper the time dependence of the force acting on the hook of the dynamometer during the whole measurement. These initial concepts may differ; try to get to a solution that everybody agrees with by mutual discussion.

Based on your first measurement, you can change your estimation of the result of the second measurement before conducting it, if you like.

Preparation before measurement

1. Put some pebbles or screws and nuts (or other weights) into the tube of fizzing tablets so that it sinks if immersed in water.
2. Attach a string to the tube so that it is possible to fasten it to the dynamometer.
3. Insert tube hanging on the string to the bottom of the graduated cylinder and fill the cylinder with enough water so that the water level is several centimetres below the rim of the cylinder.
4. Pull out the tube and dry it.
5. Switch the dynamometer to a higher range (to 50 N).
6. Connect the dynamometer to you computer and run the Vernier Logger Lite programme.
7. Set the Sampling Rate to 50 Hz and check *Continuous Data Collection*.

Measurement in the air

1. Place the dynamometer in a vertical position with the hook facing down and set it to zero (*Experiment > Zero*).
2. Hang the tube on the hook of the dynamometer and start the measurement. The programme starts to plot a graph of the force acting on the dynamometer vs. time. Before performing any changes in motion, wait until the time reaches 10 seconds, 20 seconds, 30 seconds and 40 seconds.
3. At 10 seconds after the start of the measurement move the tube ca. 10 cm higher in about one second.
4. Wait for 10 seconds and again at 20 seconds after the start of the measurement move the tube ca. 10 cm higher, but do it slowly (for about 5 seconds) this time.
5. At 30 seconds after the start move the tube 10 cm lower in about 1 second.
6. At 40 seconds move the tube 10 cm lower (approximately back to the starting position) in 5 seconds.

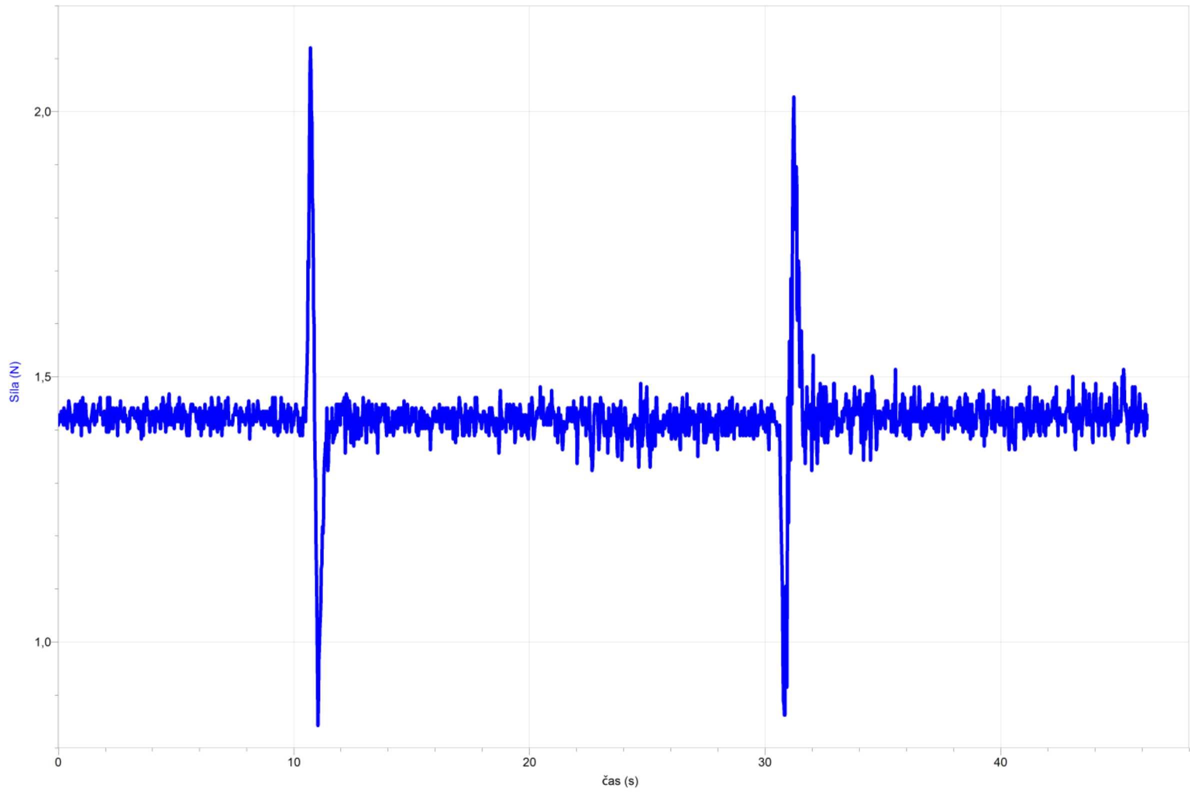
7. Stop the measurement and click *Experiment > Store Latest Run*.
8. Compare your estimation (a graph that you sketched before the measurement) with reality. If your graph differs in some parts, try to explain why.
9. If you corrected or clarified some of your misconceptions after this measurement, you can, before conducting the second measurement, change your estimation of the time dependence of the force acting on the dynamometer when you move the tube up in water.

Measurement in water

1. Hang the tube on the dynamometer and place the tube on the bottom of the graduated cylinder filled with water.
2. Start the measurement.
3. Pull the tube slowly and uniformly upward until it is fully out of the water. Continue until it is about 10 cm above the water level.
4. Stop the measurement and click *Experiment > Store Latest Run*.
5. Compare your estimation (a graph that you sketched before the measurement) with reality. If your graph differs in some parts, try to explain why.

Notes for teachers

Typical graph of the first measurement (in the air) is as follows:



One of the objectives of this first experiment is that students learn how to change the position of the tube by a slow and uniform motion because they will need it in the second measurement.

Between 0 s and 10 s the dynamometer acted on the tube by a constant force – it compensated the force of gravity, so that the tube remained in the same place and did not fall down.

At 10 s the tube was rapidly pulled upward by about 10 cm. In order to accelerate the tube upward, the dynamometer temporarily increased the force. In order to slow and stop the tube, the dynamometer temporarily reduced the force.

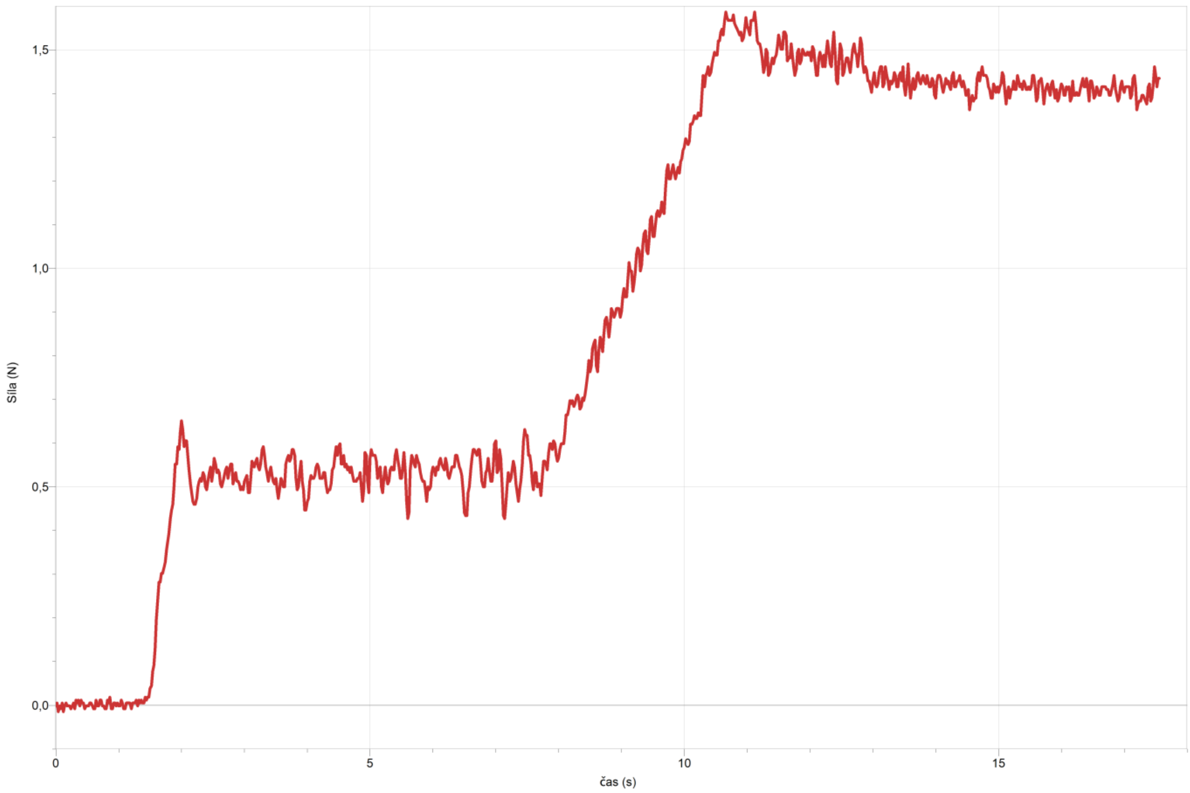
Then, until the time 20 s, the tube hanged motionless on the dynamometer.

At 20 s we began to pull the tube slowly upwards by 10 cm. Because we lifted the tube slowly, we needed only small force to get the tube in motion. This force cannot be distinguished in the "noise". To stop the tube, we needed only a small force that is again immeasurable. This took place at about 25 seconds after the start of the measurement.

At 30 s the tube was moved quickly about 10 cm lower. The graph looks the same as at 10 s, only mirrored.

At 40 s we began to lower the tube slowly by 10 cm back to the starting position. Again, the force is immeasurable.

Typical graph of the second measurement (in water) looks like this:



First, for about one second, the string was not taut; the tube was sitting on the bottom. Then the dynamometer began to lift the tube slowly and uniformly. The force exceeding the force of gravity is about 0.5 N, which is less than 1.4 N that we measured in the air. This is due to the buoyancy force of water acting on the tube. The height of the tube was 14.5 cm, the diameter of the tube was 2.8 cm. This corresponds to a buoyant force when the tube is completely immersed $F_b = V \cdot \rho \cdot g = \pi R^2 v \cdot \rho \cdot g = 0.87\ \mathrm{N}$

The difference of the forces in water and in the air is 1.4 N - 0.5 N = 0.9 N. This corresponds to the calculated buoyancy force.

At 8 s after the start of the measurement, the tube began to emerge from the water. A decreasing buoyancy force acted on the tube, and then at 11 s the whole tube emerged. The transition between 8 s and 11 s is linear.

accelerate	urychlit
acting force	působící síla
buoyant force	vztlaková síla
clarify	ujasnit si
diameter	průměr
dynamometer	siloměr
exceed	překonat
emerge	vynořit se
fasten	upevnit
fizzing tablets	šumivé tablety
force of gravity	tíhová síla
graduated cylinder	odměrný válec
mirrored	zrcadlově převrácený
motion	pohyb
motionless	nepohybující se
noise	šum, hluk
nut	matka
objective	cíl
pebbles	kamínky
plot	vykreslit
range	rozsah
rapidly	rychle
set to zero	vynulovat
sink	potopit se
sketch	načrtnout
taut	napnutý
transition	přechod
uniform motion	rovnoměrný pohyb