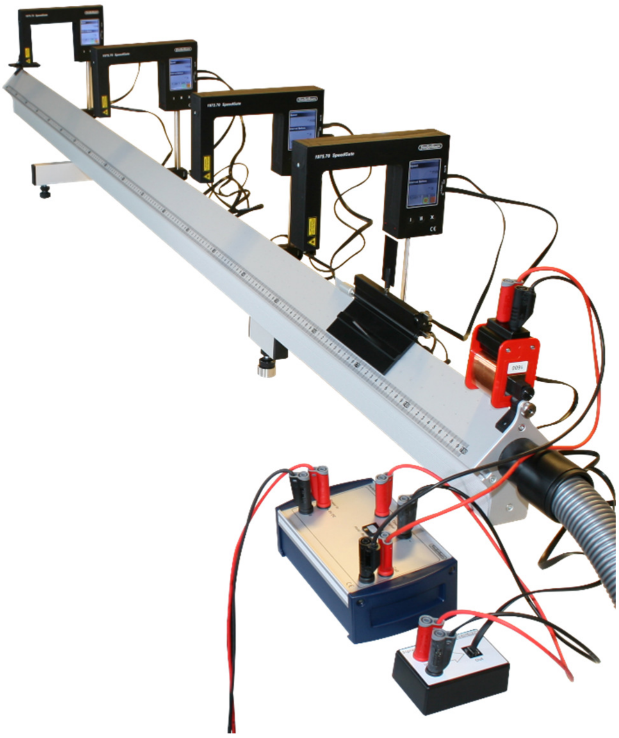
Frederiksen
Passion for science

Galileo's Incline

Experiment number 134640-EN	*Topic*	Mechanics, Kinematics			
Version 2018-01-22 / HS	*Type*	Demo experiment	*Suggested for* grade 10+	*p.*	1/4



Objective

A demonstration of constant accelerated motion.

Principle

An air track with its virtually friction-less motion constitutes a modern alternative to Galileo's inclined wooden groove.

Along the air track, several SpeedGates measure the speed as well as the time from the start of the motion to the passage of the SpeedGate.

Equipment

(Detailed equipment list on p. 4)

Air track with standard accessories
Air blower

Release mechanism
Switch Box
Signal Limiter
Power supply

Four SpeedGates incl. connection cable [1])
Four mounting brackets for SpeedGate

[1]) Any number of SpeedGates can be used.
If only one is used, you must repeat the measurement with the same inclination, and move the SpeedGate to a number of different positions.

"A piece of wooden moulding or scantling, about 12 cubits[2]) *long, half a cubit wide and three finger-breadths thick, was taken; on its edge was cut a channel a little more than one finger in breadth; having made this groove very straight, smooth, and polished, and having lined it with parchment, also as smooth and polished as pos-sible, we rolled along it a hard, smooth, and very round bronze ball…"*
Galileo: *Discourses on Two New Sciences* (1638)

[2]) Italian *braccia*. 1 *braccio* ≈ 583 mm

(Reconstruction)

Preparations

Set up the air track on a level table. Eventually make a quick adjustment of the feet to make the track horizontal. (Don't waste too much time for that. It will be inclined in a short while.) Adjust the blower to allow the cart to move smoothly.

Mount the release mechanism at one end of the air track with the finger screw. Don't use a rubber band bumper here – we want the motion to start from rest. The corresponding small soft iron blocks will fit one end of the cart.

In the other end of the track, it is a good idea to place a rubber band bumper to avoid damage when the cart reaches the end!

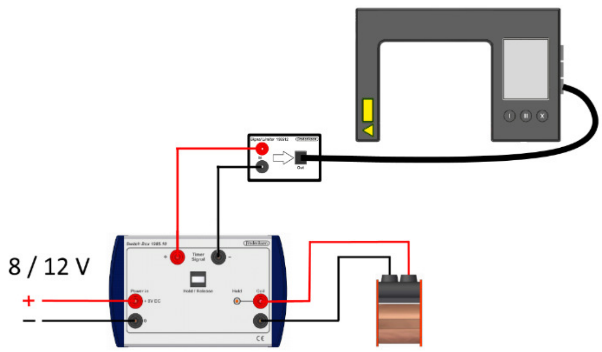
With the cart placed flush with the release mecha-nism, try to slide the closest SpeedGate until its first light ray just "touches" the flag on the cart.
Use the millimetre scale on the air track to read the position of the SpeedGate: x_0 . Write it down. Slide the SpeedGate back to a position about 25 cm further down the track. Distribute the rest of the SpeedGates along the track. All SpeedGates must face the same way.

Place one of the cylindrical 50 g weights under the single foot of the air track to make it slant a little.

Connect the Switch Box to the power supply, the coil of the Release Mechanism and the Signal Limiter as shown below.

Turn on the current in the coil. Adjust the voltage to just enough to prevent the cart from starting.

Turn off the coil again. Do this every time the coil isn't needed to prevent it from overheating.



Connect the Signal Limiter to *Chain IN* on the first SpeedGate with the modular cable included.

Each of the following SpeedGates has its *Chain IN* connected to *Chain OUT* on the previous SpeedGate.

Select primary function *Speed* and secondary function *Interval Before* on all of the SpeedGates. In this configuration, all SpeedGates will be reset when the *X* button on the first SpeedGate is pressed, and all of them will start their interval timer when a start pulse is received from the Switch Box.

Procedure

Turn on the coil, place the cart at the start point, reset the SpeedGates.

Turn off the coil with the switch – now the cart starts moving. Along its way, it will trigger the SpeedGates to stop their interval timers an to measure the speed of the cart.

It is OK to let the cart bounce off the bumper at the lower end – the SpeedGates will not make a new measurement until they are reset.

(In case you don't have as many SpeedGates as you want measurements, you will need to repeat this procedure

Possible extension

The above procedure is all you need for a quick demonstration.

It is possible to extend the experiment to a thorough, quantitative investigation.

You will then repeat the measurements with different, known inclination angles θ .

Compare the measured accelerations (se next paragraph) to the component of g (the acceleration due to gravity) that is parallel to the track:

$$a_{\text{Theory}} = g \cdot \sin(\theta)$$

You need a precise way to measure θ :

With the air track precisely horizontal, measure the distance from the table top to each of the ends of the track.

For each angle of inclination, do the same. Calculate how much each end has been lifted or lowered.

Measure the distance between the two points of the track that you used above.

Find the angle using trigonometry.

Theory

For motion with a constant acceleration a, you expect the speed v to increase proportionally with time t:

$$v = a \cdot t$$

Likewise, the position s is expected to increase proportionally with the time squared, or more precisely:

$$s = \frac{1}{2} a \cdot t^2$$

This simple form of the equations require both the initial speed and the start position to be zero. We do our best to accomplish that, but should be prepared for minor deviations. The more complete formulae below will come into play:

$$v = a \cdot t + v_0$$

$$s = \frac{1}{2} a \cdot t^2 + s_0$$

(The completely general formula

$$s = \frac{1}{2} a \cdot t^2 + v_0 \cdot \mathrm{t} + s_0$$

isn't suited for the graphical analysis described below. In practice, it is not necessary to use it.)

Calculations

Enter the data in a spreadsheet like this:

x_0:		cm			
x	s	t	v	t^2	s
cm	cm	s	m/s	s^2	m
	0			0	0

The shaded cells correspond to directly measured values. The value x is the position of a SpeedGate and t and v are the *Interval time* and the *Speed* read off that SpeedGate. The value s (in cm) is simply

$$s = x - x_o$$

Columns for t^2 and s (m) are calculated from t resp. s (cm).

Set up two graphs: One for $v(t)$ and one for $s(t^2)$. Add a trend line for each graph.

If you have been careful – and a little bit lucky – both data sets can be very well approximated with a straight line through Origo.

If you experience that the *first* data points (for t=0) are a bit off – simply delete that line from the table.

Discussion and evaluation

The terms s_0 and v_0 both combine two different errors:

It is difficult to obtain a precise value for x_0.

And there will probably be a little residual magnetism in the core of the electromagnet after the current was cut.

Apart from these small errors – that make the trend lines miss the Origo – the results should be impressively consistent with the theory.

If time permits, the value for a that can be extracted from the two graphs could be compared and should of course be very closely the same.

Teacher's notes

Concepts used

Speed
Acceleration

Mathematical skills

Simple expression evaluation
Graphs in a spreadsheet
(Trigonometry)

About the equipment

The newest version of the electric launcher (195210) is recommended.

Old version (195200) draws higher current, tends to overheat, and has an unnecessarily strong pull. You may want to stick small patches of paper over the core with adhesive tape to make it just strong enough to hold the cart.

Detailed equipment list

Specifically for the experiment

195050 Air track (incl. accessories)
197070 Air blower

197570 SpeedGate (Qty. 4)
195055 Mounting bracket for 197570 (Qty. 4)

195210 Electric launcher
198510 Switch Box
198512 Signal Limiter

Standard lab equipment

361600 Power supply (-or similar)

105720 Safety cable, silicone, 50 cm, black (Qty. 2)
105721 Safety cable, silicone, 50 cm, red (Qty. 2)
105740 Safety cable, silicone, 100 cm, black
105741 Safety cable, silicone, 100 cm, red

Spare parts

197571 Cable modular crossed 2m
(This cable is included with a SpeedGate)