Velocity-independent and velocity-dependent friction with Demo-Track and Timer 4-4 (Item No.: P1198105)

Curricular Relevance

Area of Expertise:	Education Level:	Topic:	Subtopic:	Experiment:
Physik	Klasse 7-10	Mechanik	Lineare Bewegung	

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Intermediate	20 Minutes	20 Minutes	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

friction, decelerated motion, felt brake, kinetic friction (sliding friction, dynamic friction), static friction, magnetic brake, eddy current brake, velocity-dependent acceleration, resolution of forces

Overview

Introduction

Friction slows every movement. The aim of this experiment is to demonstrate the influence of friction and the difference between various types of friction by way of a demonstration track and a cart that performs a decelerated motion. The friction between a piece of felt and a metal surface is an example of kinetic friction (sometimes also called sliding friction or dynamic friction). The frictional force in the case of kinetic friction is independent of the velocity of the motion. The friction that is caused by an eddy current brake, on the other hand, is an example of a velocity-dependent frictional force. In this case, it is proportional to the velocity.

Educational objective

If the motion of an object is decelerated due to negative acceleration, its motion changes. Depending on the type of brake, it displays different types of motion. The aim of this experiment is to use friction in order to demonstrate the difference between uniformly decelerated motion and velocity-dependent deceleration.

Related topics

A simple demonstration concerning velocity-independent deceleration can be found in the experiment P1198905 "Uniformly decelerated motion". In this experiment, the cart is decelerated on an inclined track by the gravitational acceleration to which it is subjected.

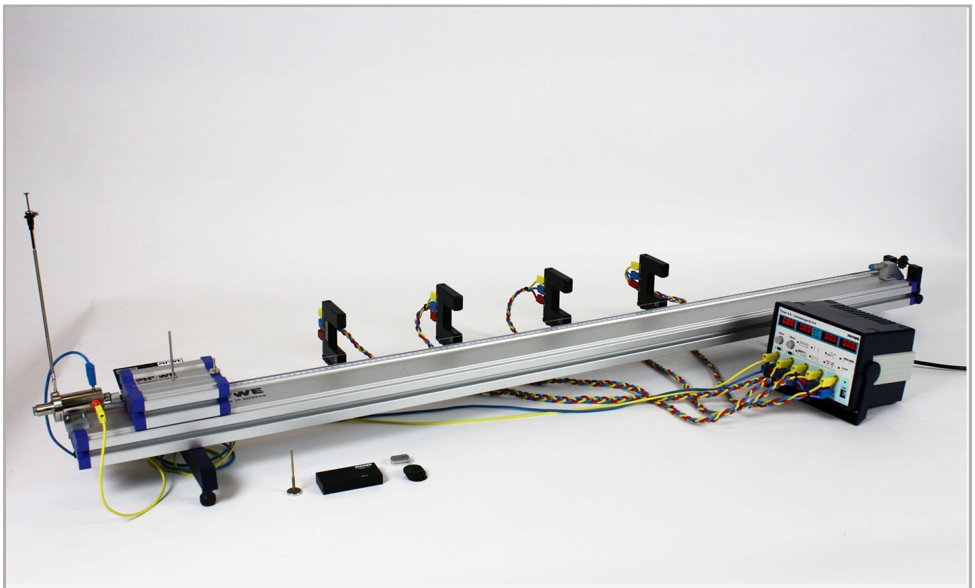

Figure 1: Experiment set-up

Equipment

Position No.	Material	Order No.	Quantity
1	Timer 4-4	13604-99	1
2	Starter system for demonstration track	11309-00	1
3	Demonstration track, aluminium, 1.5 m	11305-00	1
4	Cart, low friction sapphire bearings	11306-00	1
5	Light barrier, compact	11207-20	4
6	Friction accessory for low friction cart	11310-00	1
7	End holder for demonstration track	11305-12	1
8	Weight for low friction cart, 400 g	11306-10	1
9	Magnet w.plug f.starter system	11202-14	1
10	Holder for pulley	11305-11	1
11	Pulley for demonstration track	11305-10	1
12	Shutter plate for low friction cart, width: 100 mm	11308-00	1
13	Weight holder, silver bronze, 1 g	02407-00	1
14	Tube with plug	11202-05	1
15	Holder for light barrier	11307-00	4
16	Connecting cord, 32 A, 1000 mm, red	07363-01	4
17	Connecting cord, 32 A, 1000 mm, yellow	07363-02	5
18	Connecting cord, 32 A, 1000 mm, blue	07363-04	5
19	Slotted weight, black, 10 g	02205-01	4
20	Plasticine, 10 sticks	03935-03	1
21	Slotted weight, blank, 1 g	03916-00	20
22	Silk thread, l = 200 m	02412-00	1

Tasks

1. Determination of the influence of kinetic friction and an eddy current brake on the motion with a certain initial velocity.
2. Determination of the influence of kinetic friction and an eddy current brake on the motion with a constant accelerating force.

Set-up and procedure

Set-up

Set the experiment up as shown in Figure 1:

1. Position the starter system at the left end of the track. Please note that, in order to start the cart with an initial momentum, the starter system must be installed so that the cart receives an impulse from the ram of the starter system (Fig. 2).

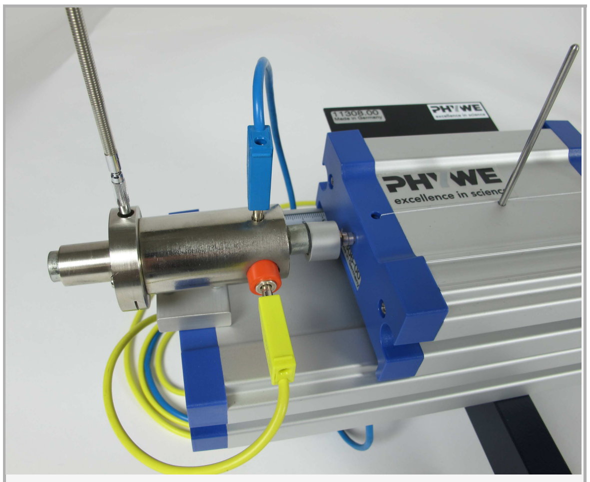

Fig. 2: Starter system for providing the necessary impulse

2. Attach a plasticine-filled tube to the end holder at the right-hand end of the track in order to stop the cart without a strong impact (Fig. 3).

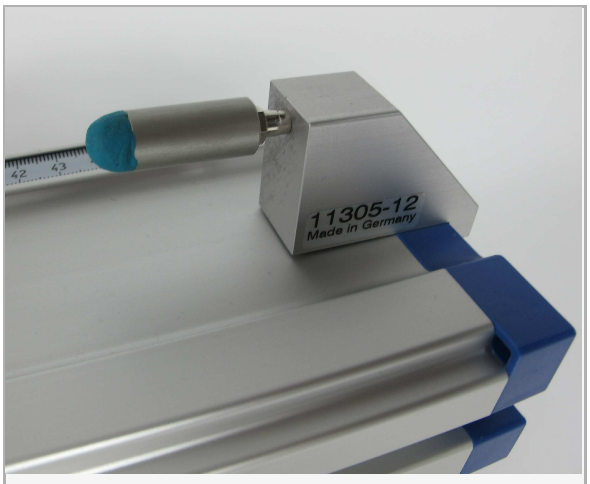

Fig. 3: End holder with plasticine

3. Install the pulley with the holder for the pulley at the right-hand end of the track and add the incremental wheel.
4. Fasten the shutter plate on the cart (w = 100 mm). Insert the end of the thread from above through the vertical hole at the back of the end cap of the cart and secure it in place by plugging the magnet with a plug into the horizontal opening (see Fig. 2).
5. Lay the thread over the incremental wheel of the light barrier and knot its end onto the weight holder so that the latter is suspended freely just below the wheel when the cart is in the starter system (see Fig. 4). Ensure that the thread is parallel to the track. Important: Ensure that there are no additional weights on the weight holder during part *a)* of the experiment!

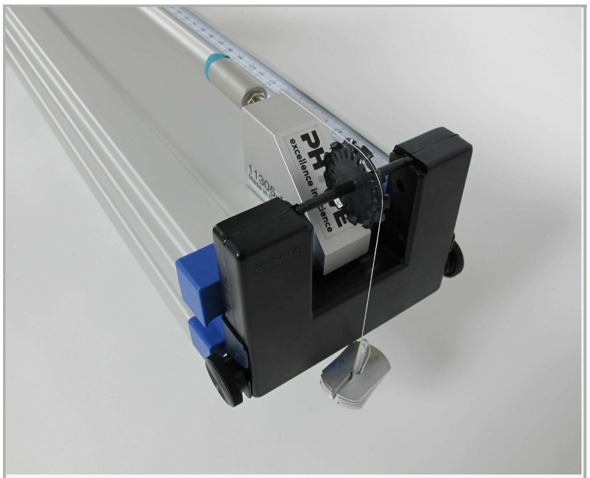

Fig. 4: Positioning of the weight holder

6. In order to compensate for any friction effects of the cart and also for the weight force of the empty weight holder, the track must be slightly inclined by way of the adjusting screws at the track bases so that the cart is still just about prevented from rolling to the right.
7. Install the four light barriers on the track by way of the light barrier holders and distribute them evenly over the track. Ensure that the back part of the shutter plate on the moving cart can pass through all of the light barriers before the weight holder touches the floor (see Fig. 5).

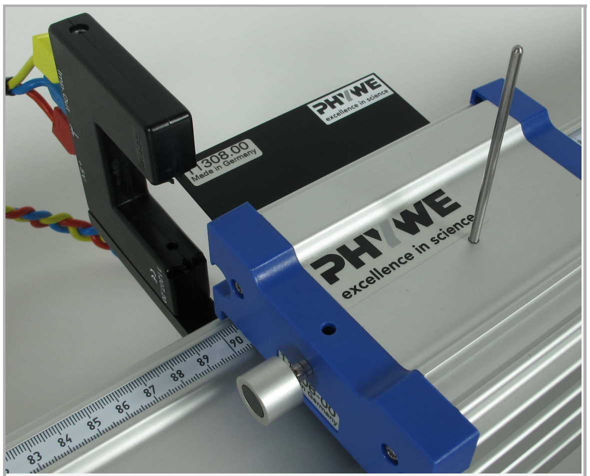

Fig. 5: Release of a light barrier following the passing of the shutter plate

8. Connect the four light barriers from the left to the right to the sockets in the fields "1" to "4" of the timer. In doing so, connect the yellow sockets of the light barriers to the yellow sockets of the measuring instrument, the red sockets to their red counterparts, and the blue sockets of the light barriers to the white sockets of the timer (see Fig. 6).

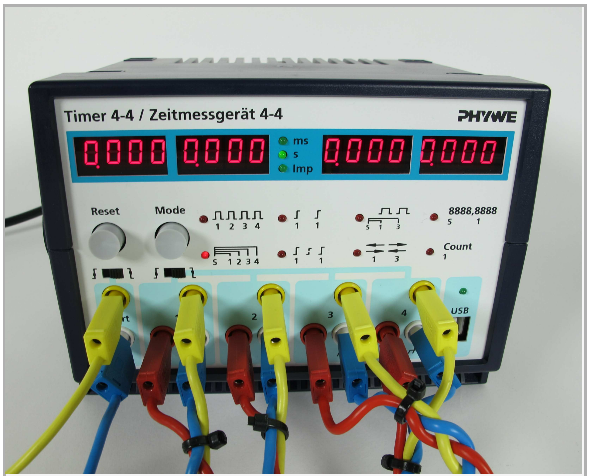

Fig. 6: Connection of the light barriers and starter system

9. Connect the starter system to the two "Start" sockets of the timer. Ensure that the polarity is correct. Connect the red socket of the starter system to the yellow socket of the timer.
10. In order to select the triggering edge, push the two slide switches of the timer to the right, i.e. to "falling edge" ( ).
11. Screw the felt brake (taken from the set of friction accessories) into the vertical hole at the front of the end cap of the cart and secure it at the desired height by way of the knurled screw (Fig. 7). The felt should push against the track in such a manner that, following the release of the starter system, the cart just about stops before the weight holder (without any weights attached) touches the floor.

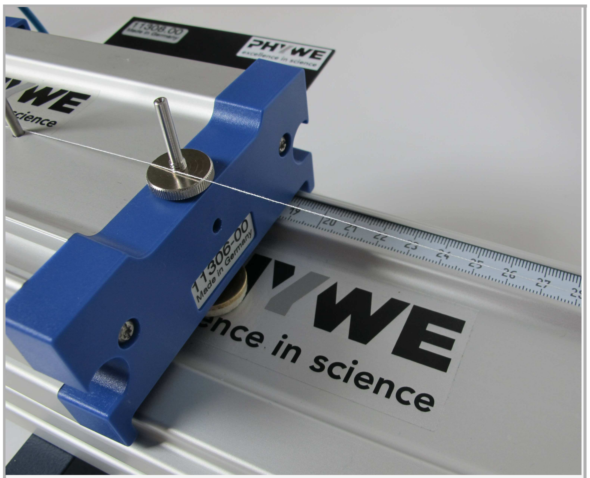

Fig. 7: Installation of the felt brake on the cart

Procedure

a) Deceleration of the cart from its initial velocity by way of friction:

1. Due to the impulse from the starter system, the cart receives an initial velocity while, at the same time, due to the friction of the felt brake on the track, it is also subject to acceleration in the opposite direction of its velocity.
2. First, measure the times $t_1 \dots t_4$ from the start up to reaching the corresponding light barriers in mode 2 ( ). Then, perform a measurement in mode 1 ( ) in order to determine the corresponding velocities. During this measurement, the shading times $\Delta t_1 \dots \Delta t_4$ of the four light barriers are determined. These are then used in order to calculate the average velocity of the cart passing through the light barriers based on the length of the shutter plate (100 mm).
3. Record the times for 1 to 3 repetitions. Prior to every recording process, press the "Reset" button in order to reset the display.
4. Reposition the light barriers and perform two additional series of measurements as described hereinabove. For one measurement, position the first light barrier close to the start position of the cart in order to determine v_0. Ensure that there is no contact between the starter system and the magnet with a plug after the start.
5. Replace the felt brake with the magnetic brake (Fig. 8).

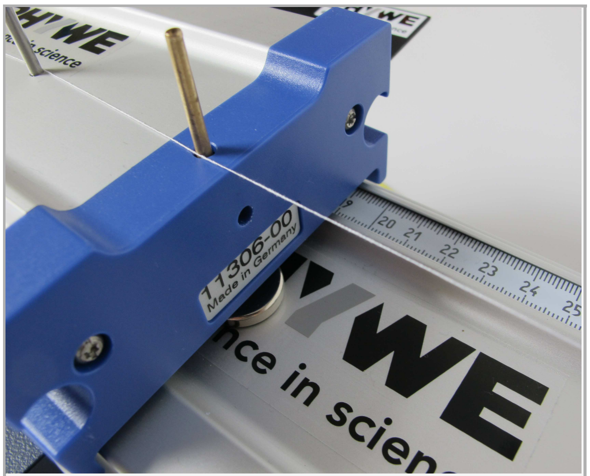

Fig. 8: Installation of the eddy current brake on the cart

6. Adjust the distance between the magnet and the track so that, following the triggering of the starter system, the cart stops before the weight holder touches the floor. However, the magnet must not touch the track (see Fig. 9).

Fig. 9: The magnet is located close to the track

7. Perform the measurement series as described for the felt brake.

b) Acceleration of the cart under the influence of friction with a constant force pulling on the cart:

1. Turn the starter system around so that its ram moves away from the cart when it is triggered. As a result, the cart will be started without any impulse (see Fig. 10).

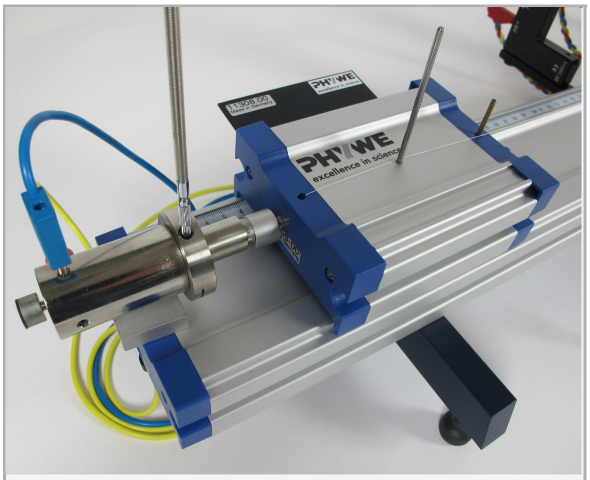
Fig. 10: Starter system without an impulse

2. Decrease the distance between the magnetic brake and the track as much as possible without the magnet rubbing against the track.
3. Position different weights with masses between 3 g and 40 g on the weight holder and perform a separate measurement for each of the weights as described in part *a)*.
4. The cart accelerates once it is released. When the weight holder touches the floor, the brake stops the cart or the cart hits the end holder.
5. Replace the magnetic brake with the felt brake.
6. Adjust the pressure of the felt brake on the track so that the cart still just does not move when 10 g are placed on the weight holder, also not when it is slightly nudged.
7. Perform measurements for different masses between 20 g and 40 g.

Observation and results

Observation

When the cart is accelerated by weights suspended from it, the two brakes exhibit a different behaviour. With the magnetic brake, the cart starts to move even in the case of small accelerating forces and it moves at constant velocity. In the case of greater forces, it is accelerated at first before it finally reaches a constant terminal velocity.
In the case of the felt brake, greater forces are required for starting the motion of the cart. Once the force is sufficient, the cart continues to move in a uniformly accelerated manner until the weight holder touches the floor.

Evaluation

a) Deceleration of the cart from its initial velocity by way of friction:

1. Based on the measurements of $t_1 \dots t_{12}$ and $\Delta t_1 \dots \Delta t_{12}$ for both types of brakes, calculate the mean values $t_{1m} \dots t_{12m}$ and $\Delta t_{1m} \dots \Delta t_{12m}$.
2. The shading times are used to determine the velocities $v_i(t_{im}) = w / \Delta t_{im}$ with the shutter plate length $w = 0.1$ m.
3. In order to reduce the influence of the initial static friction, the starting point t_0 of the measurement must be assigned to the time t_1 at which the cart reaches the first light barrier. For this purpose, the differences of every measuring point with regard to this starting point must be determined.
   $t'_i = t_{im} - t_0 \text{ with } t_0 = t_{1m}$.
   As a result, the following applies to the initial velocity of the measurement: $v_0 = v_{1m}$.
4. Based on the velocities, the accelerations at the corresponding light barriers are determined with
   $a_i = \frac{v_i}{t'_i} = \frac{w \,/\, \Delta t_{im}}{t'_i}$.
   Note: Due to the assignment of the starting point t_0 to t_1, there is no acceleration for a_1.
5. Table 1 shows the values of an example measurement. The velocity and acceleration are plotted as a function of the time t' for both types of brakes:
   - In the case of kinetic friction with the felt brake, the acceleration decreases linearly over time and the braking acceleration (deceleration) is constant and not velocity-dependent (see Fig. 11).

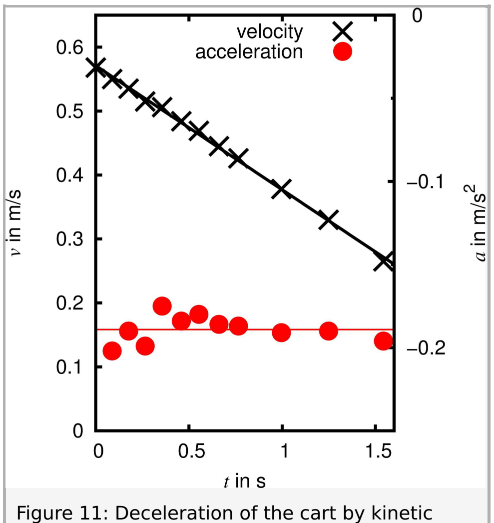

Figure 11: Deceleration of the cart by kinetic friction with the felt brake

   - In the case of eddy current friction with the magnetic brake, the acceleration decreases rapidly at first and then more slowly. Compared to a straight line, the velocity-time-curve is bent towards the bottom. At the beginning, deceleration is high (high negative acceleration) before it decreases towards the end of the motion (see Fig. 12).

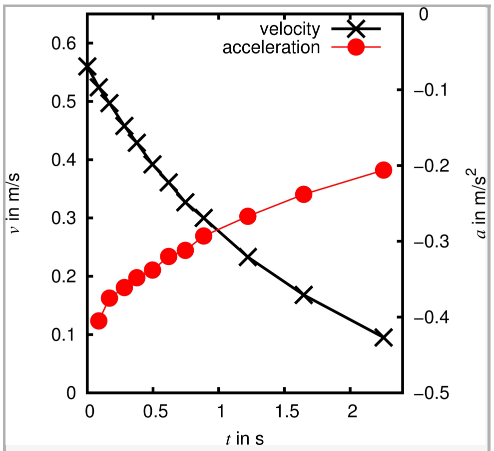

Figure 12: Deceleration of the cart by eddy current with the felt brake

Table 1: Measurement example concerning the deceleration of the cart with a certain initial velocity due to kinetic friction with the felt brake and due to eddy current friction with the magnetic brak

Felt brake					Magnetic brake				
t_m in s	t' in s	Δt_m in s	v in m/s	a in m/s²	t_m in s	t' in s	Δt_m in s	v in m/s	a in m/s²
0.023	0.000	0.176	0.568	–	0.023	0.000	0.179	0.560	–
0.111	0.088	0.182	0.550	−0.202	0.110	0.087	0.191	0.524	−0.405
0.199	0.176	0.187	0.535	−0.190	0.191	0.168	0.201	0.497	−0.375
0.288	0.265	0.194	0.515	−0.199	0.305	0.282	0.218	0.458	−0.361
0.379	0.356	0.198	0.506	−0.175	0.401	0.377	0.233	0.429	−0.348
0.482	0.459	0.207	0.484	−0.184	0.519	0.496	0.255	0.392	−0.338
0.576	0.553	0.213	0.469	−0.180	0.643	0.619	0.277	0.361	−0.320
0.685	0.661	0.225	0.445	−0.186	0.770	0.746	0.306	0.327	−0.312
0.788	0.765	0.235	0.426	−0.187	0.909	0.886	0.333	0.300	−0.293
1.019	0.996	0.264	0.378	−0.191	1.245	1.222	0.429	0.233	−0.267
1.272	1.249	0.303	0.330	−0.190	1.670	1.647	0.597	0.168	−0.238
1.566	1.543	0.377	0.265	−0.196	2.279	2.255	1.050	0.095	−0.206

b) Pulling of the cart with constant force under the influence of friction

1. The shading times are used to determine the velocities $v_i(t_{im}) = w\,/\,\Delta t_{im}$ with the shutter plate length $w = 0.1$ m.
2. Magnetic brake: The velocities for different weights are plotted over time. In order to be able to compare the situations for the various weights, a joint diagram is created for these weights.
    - In the case of eddy current friction (compare Fig. 13), the velocity increases quickly at first before it increases more slowly. The acceleration decreases over time and approaches zero when the cart reaches a constant velocity.

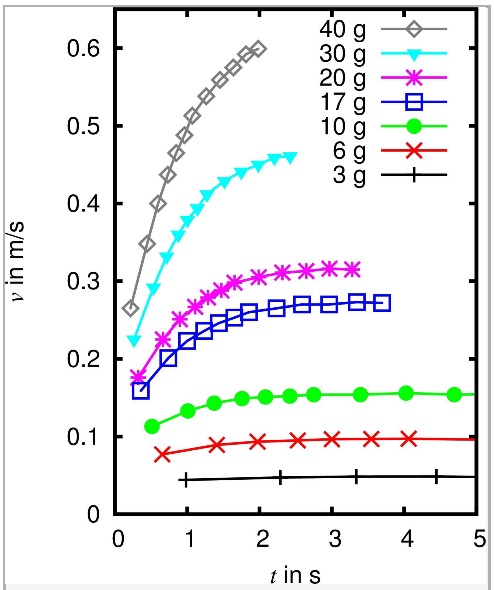

Figure 13: Magnetic brake with different accelerating masses

- The force pulling on the cart can be resolved into a part responsible for the acceleration and a part that counteracts the acceleration due to friction. The latter increases in line with the velocity until it compensates for the part of the force that is responsible for the acceleration so that this part becomes zero.
- The limit velocity can be read off the velocity-time diagram and it can be plotted against the force for every force pulling on the cart. The result is a curve like the one shown in Figure 14. Its inversion shows the braking force as a function of the velocity. In this example of a linear relationship

$$F = C \cdot v$$

the gradient in Figure 14 corresponds to the reciprocal of the constant $C = 1 / (1.56\,\text{m/(s·N)}) = 0.64\,\text{N·s/m}$. This constant C depends on the distance between the magnet and the track, i.e. on the magnetic flux density on the track and on the conductivity of the track.

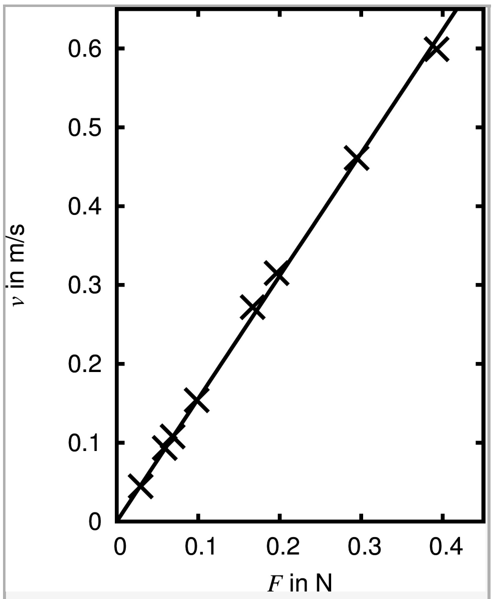

Figure 14: Eddy current brake. Terminal velocity as a function of the force pulling on the cart.

3. Felt brake: The velocities are plotted as a function of the time t for the various weights.
   - In the case of kinetic friction (compare Fig. 15), the cart either does not start at all if the force is too weak or it performs a uniformly accelerated motion – but with less acceleration compared to the motion without a brake.

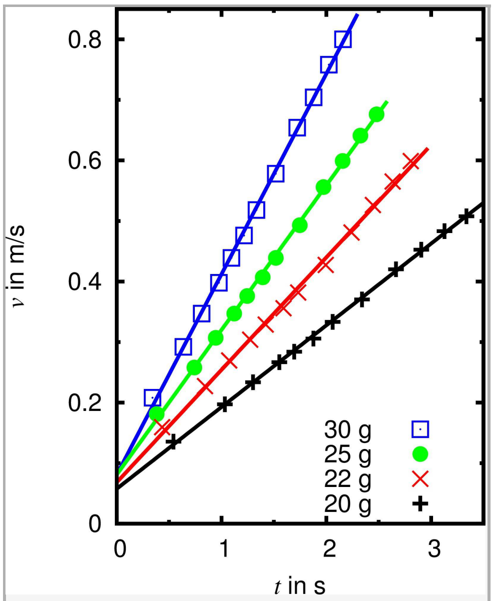

Figure 15: Felt brake with different accelerating masses

- The force F_a that accelerates the cart comprises a part F_g, which is responsible for the acceleration due to the attached weights, and a part F_f, which counteracts the acceleration due to friction. If the frictional force F_f is a constant, the weight force F_g with the added weights must be greater than the frictional force so that the cart moves:
$$F_g > F_f .$$
The resulting force is a combination of both forces:
$$F_a = M \cdot a \text{ and } F_a = F_g - F_f \text{ with } F_g = m \cdot g$$
with *M* as the total accelerated mass (mass of the cart plus added weights), *m* as the mass on the weight holder, and *g* as the gravitational acceleration.
- The (*v*, *t*)-diagram (Fig. 15) can be used to determine the acceleration for the respective weights based on the gradients. If the acceleration is plotted as a function of the weight force F_g (compare Fig. 16), the intersection with the *x*-axis represents the frictional force F_f, since the motion of the cart commences in the case of higher weight forces F_g.

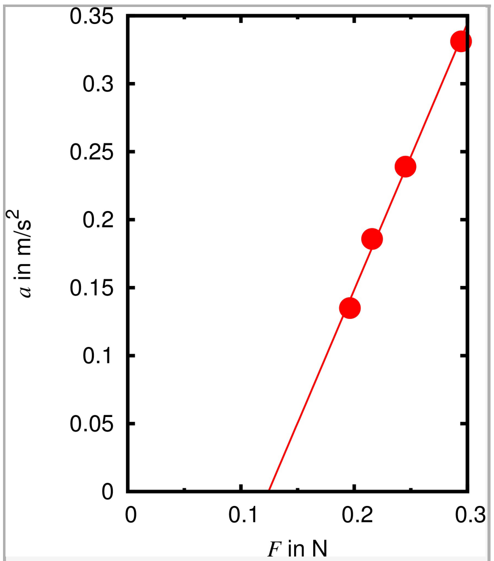

Figure 16: Kinetic friction brake. Acceleration as a function of the force pulling on the cart.

Since F_f is assumed to be constant, the reciprocal of the gradient of the graph results in the total mass *M*:
$$\frac{F_a}{M} = a = \frac{1}{M} \cdot F_g - \frac{F_f}{M}$$

- The measurement example yields a total mass $M = 1/(1.96\ \text{m}/(\text{s}^2\cdot\text{N})) = 0.510$ kg and a frictional force $F_f = 0.13$ N, which corresponds to a counterweight of 13 g.

Note

1. In order to ensure that the total mass $M = m_c + m$ is constant during the last part of the experiment, the weights that are to be placed on the weight holder later on can be placed on the cart first.
2. This experiment involves the recording of numerous measurement values. Since this may be rather time-consuming, we recommend performing only a few repetitions or no repetition at all during part *b)*. Instead, several series of measurements should be performed with different weights. The time measurements show only minor variations if the experiment is performed correctly, whereas a larger number of measurement series provides a better understanding of the different braking mechanisms. Part *a)* can also be performed without averaging. In this case, the measuring inaccuracy is in the range of approximately 2 %.
3. In order to decrease the distance between the weight holder and the incremental wheel, the thread can be shortened by turning the magnet with a plug on the cart several times, thereby winding the thread up.