AE405 LAB-2 Newton's 2nd law demonstration track

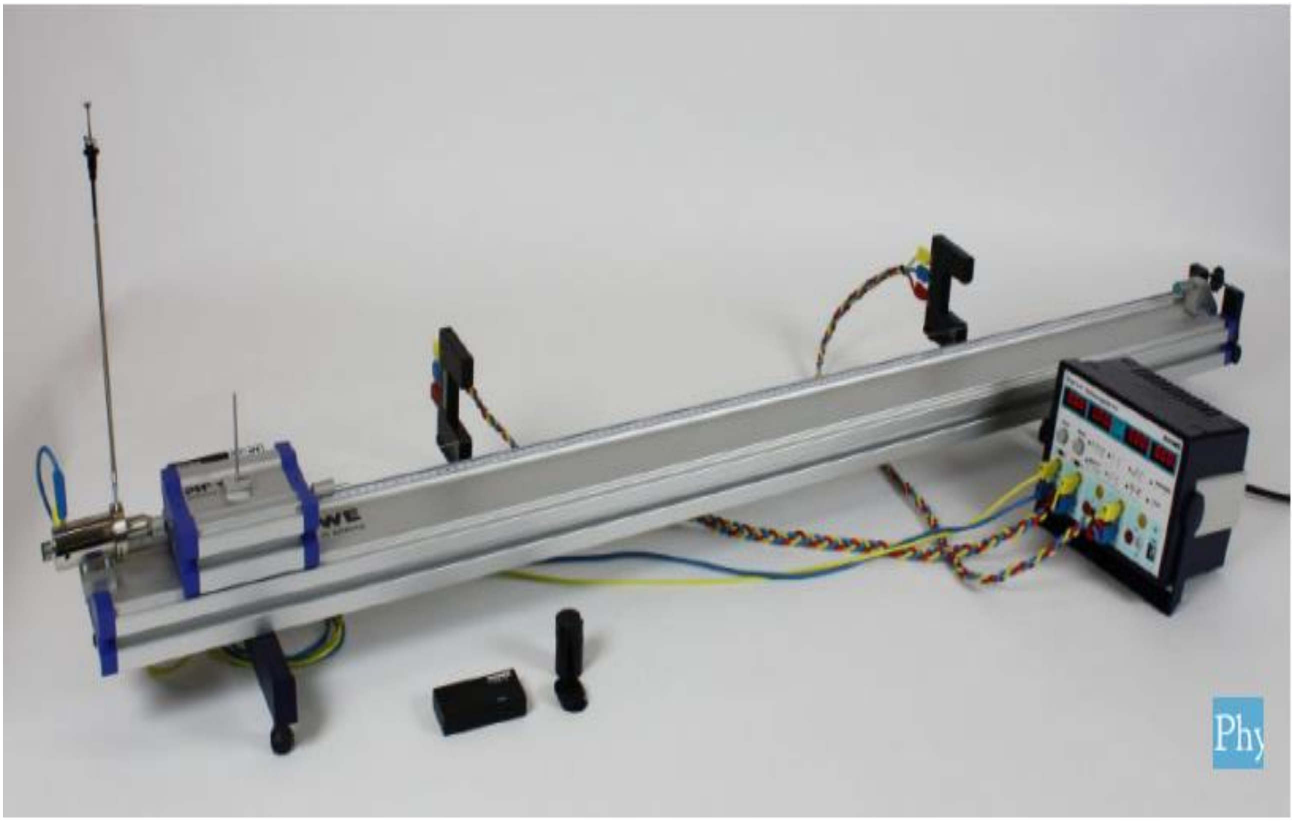


Fig.1: Experimental Setup

PRINCIPLE AND TASK

Understanding the relation between mass and acceleration according to Newton's second law for various inertial masses and different accelerating forces.

1. Determination of the cart acceleration as a function of the accelerated mass
2. Determination of the acceleration as a function of the force.

The distance-time law, the velocity time law, and the relationship between mass, acceleration and force are determined with the aid of the demonstration track rail for uniformly accelerated motion in a straight line.

Equipment

PHYWE Timer

Light barrier

Slotted weight, black, 1g

Slotted weight, black, 10g

Slotted weight, black, 50g

Starter System for demonstration track

Magnet w.plug f.starter system

Tube with plug

Plasticine, 10 sticks

Silk thread, l=200m

Weight holder, silver bronze, 1g

Shutter plate for low friction cart, width:100 mm

Needle with plug

Demonstration track, aluminium, 1.5 m

Cart, low friction sapphire bearings

Pulley for demonstration track

Holder for pulley

Weight for low friction cart, 400g

Pulley, moveable, dia.40mm

End holder for demonstration track

Holder for light barrier

Portable Balance

Connecting cord, 32A, 1000 mm, red

Connecting cord, 32A, 1000 mm, blue

Connecting cord, 32A, 1000 mm, yellow

INTRODUCTION

Applications of Newton's second law of motion are widely seen in our daily life and technology, for example:

- Pushing and pulling a cart
- A rocket launch
- Forces needed to accelerate or decelerate a vehicle

Inertial mass is the mass giving the resistance of a body to changes in its state of motion when responding to all types of force. Gravitational mass is the mass of a body as measured by the strength of the gravitational force experienced by the body when in the gravitational field g.

When a body is affected by a constant force, it will undergo a constant acceleration. The change of motion is proportional to the accelerating force. In this experiment, the relation between the acceleration of a cart on the demonstration track and its mass as well as the relation between its acceleration and the accelerating force will be studied.

PROBLEMS

Determination of:

1.Distance travelled as a function of time

2.Velocity as a function of time

3.Acceleration as a function of the accelerated mass

4.Acceleration as a function of force

THEORY

According to Newton's second law the change of motion of an object is proportional to the affecting force:

$$\vec{F} = m \cdot \frac{d^2 \vec{x}}{dt^2} = m \cdot \frac{d \vec{v}}{dt} = m \cdot \vec{a}$$

a) Acceleration as a function of the total inertial mass

The total mass is given by the mass of the cart M, consisting of the empty mass M_0 of the cart and the mass M_{sw} of the additional slotted weights, as well as the constant mass m of the weight holder including the slotted weights.

The measured times t_i and Δt_i yield the acceleration of the cart a_i, instantaneously, using the velocity-time equation and the shutter plate width w. Within the limits of the measurement accuracy, the acceleration is expected to be identical for both light barriers thus the mean acceleration should be used for the further approach.

$$a_m = \frac{a_1 + a_2}{2} = \frac{w(t_1 \cdot \Delta t_1 + t_2 \cdot \Delta t_2)}{2}$$

The diagram reveals a linear dependency which is in agreement with Newton's second law of motion. The primal force causing the motion is the gravitational force.

$$F_G = m \cdot g$$

which consists of the gravitational acceleration g and the mass of the weight holder m. Due to the fact that the weight holder is directly connected to the cart, the gravitational force is equal to the force F_{mot} which causes the motion of the entire system:

$$F_G = m \cdot g = (M + m) \cdot a = F_{mot}$$

That results in the linearity between acceleration and the reciprocal mass

$$a = \frac{m \cdot g}{M+m} \propto \frac{1}{M+m}$$

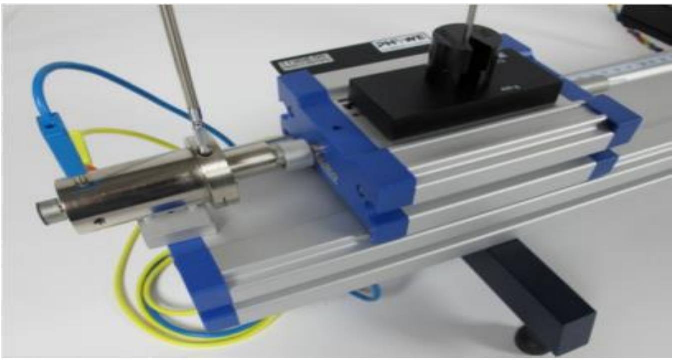
b) Acceleration as a function of force

From the balance of forces also follows a linearity between acceleration and the gravitational force

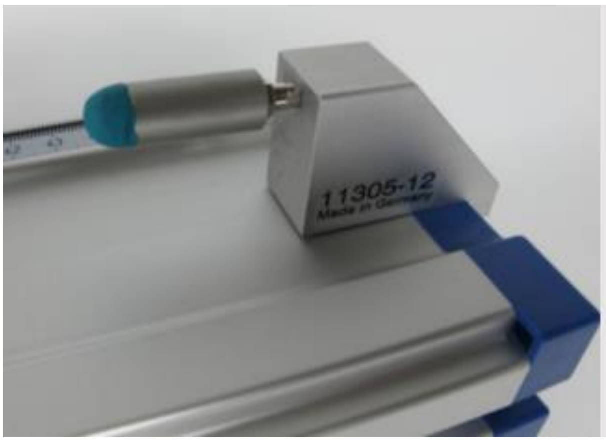
$$a = \frac{F_G}{M+m} \propto F_G$$

SETUP

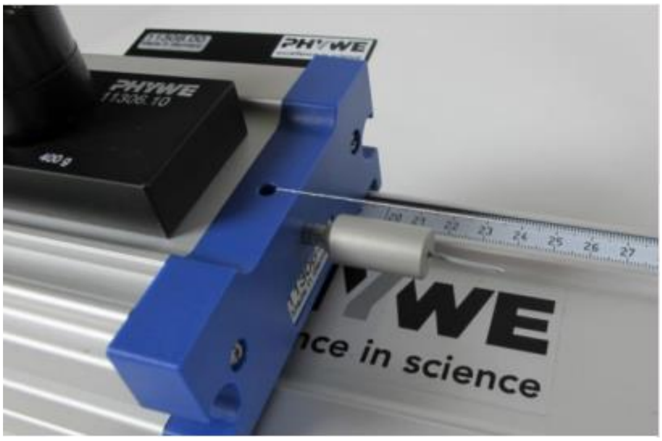
1. The experimental set-up is shown in the figure 1. To compensate marginal friction effects, the demonstration track has to be adjusted by the set-screws at the track bases. Turn the screws so that you cause a slight inclination of the track but avoid that the cart will start to roll rightwards.
2. Mount the starter system on the left end of the track. The plunger has to point away from the cart so it can be released without an initial momentum.



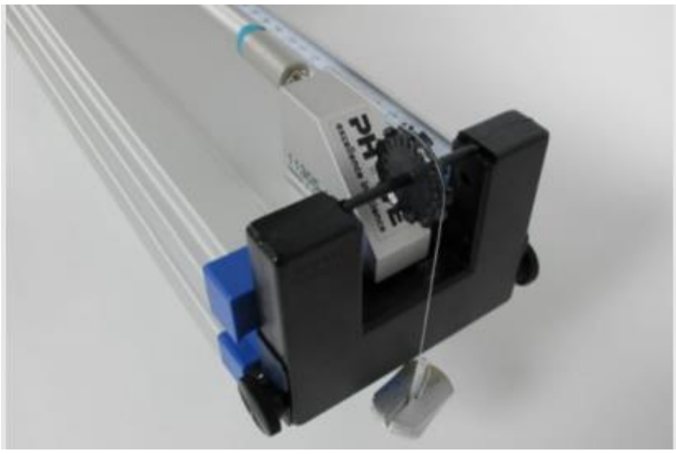
3. Place the end holder at the far end of the track and insert the tube filled with Plasticine. This will prevent a hard collision and the cart will brake gently. The pulley for demonstration track has to be attached to the right end of the track by the holder with the incremental wheel inserted. Assemble the cart with the magnet to the left side and the shutter plate.



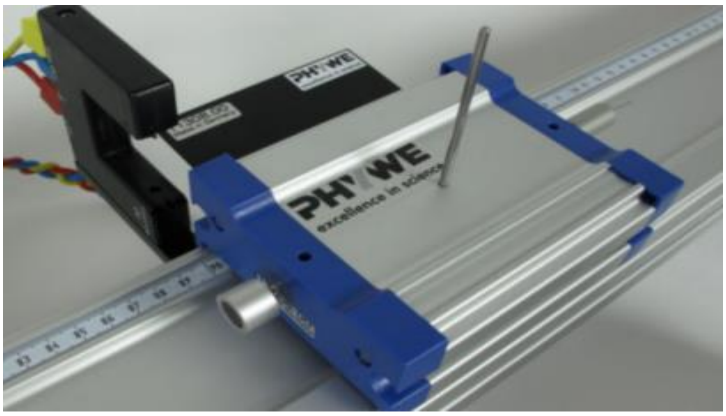
4. The thread end is set in the right vertical drilling of the cart and fixed due to the insertion of the needle



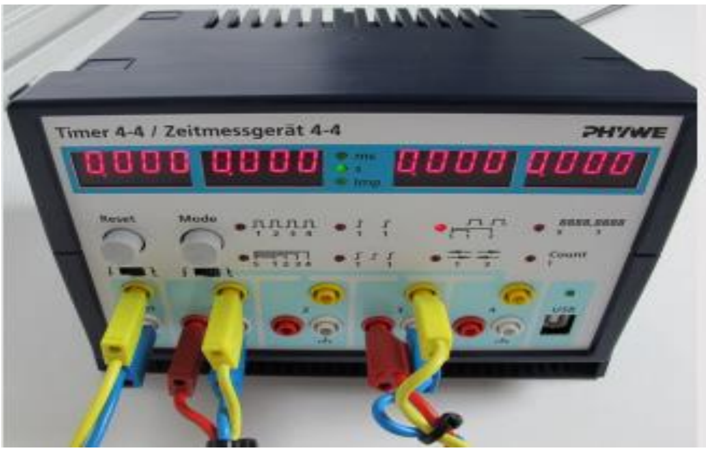
5. The silk thread is put over the incremental wheel of the pulley and knotted to the weight holder, which should hang freely directly below the pulley. The weight holder including 5 to 20 slotted weights (1 g each) serves as a constant accelerating force. Please note that the thread always runs parallel to the track. The mass of the cart can be adjusted using the black lacquered weights.



6. Two light barriers are mounted on the track by the holders in an even distribution. Make sure that both light barriers can be passed by the rear part of the shutter plate when rolling the cart.



7. The light barriers have to be connected to the jacks in the timer panels “1” and “3”. Therefore, the yellow light barrier jacks are connected to the yellow jacks of the timer, the red jacks to the red jacks, and the blue jacks of the light barriers to the white jacks of the timer. The starter system is connected to the “Start” socket of the timer. Be aware of the proper polarity, the red jack of the starter system has to be connected to the yellow jack of the timer. The two slide switches of the timer set the trigger edges and are moved to the right position for “falling edge”.



PROCEDURE

a) Acceleration as a function of the total inertial mass

In the experiment, the cart will be forced to a uniform accelerated motion due to the descent of the weight holder. The acceleration of the cart has to be observed regarding the total inertial mass and the accelerating mass, as well. Therefore, the mass of the assembled cart (but without any of the black lacquered additional weights) has to be determined by use of the balance. The cart is released from the starter system and is forced to a constant acceleration until the weight holder reaches the floor.

To determine the acceleration of the cart, the measurement is performed in timer mode 5. In this setup, both light barriers measure two times at once. The elapsed time t_i from the start until the cart reaches each of the light barriers is shown in the displays 1 and 3 of the timer, whereas the interruption time Δt_i during the passing of the shutter plate through the optical path of a light barrier is displayed in screens 2 and 4.

The velocity-time equation gives us the acceleration of the cart:

$$v(t) = a \cdot t \;\rightarrow\; a = \frac{v(t)}{t} = \frac{w/\Delta t}{t}$$

Using a shutter plate width w=100 mm. To evaluate the acceleration as a function of the mass of the cart, a whole series of measurements has to be carried out, where the mass of the cart is increased in steps of about 10 g to 50 g. Meanwhile, the mass of the weight holder has to remain constant.

a) Acceleration as a function of force

In the second part of the experiment, the acceleration should be measured as a function of the accelerating force. Therefore, a second series of measurements has to be performed, at which the total mass of the system remains constant while the accelerating force is altered. That can be achieved by a mass transfer from the cart to the weight holder.

It is recommended to initially place about ten slotted weights of 1 g on the cart. For each measurement, gradually transfer one of the weights from the cart to the weight holder. The accelerating mass should not exceed a maximum of 20 g.

NOTICE

- To reduce the distance between weight holder and incremental wheel, the thread length can be shortened by multiple twists of the needle with plug in the frontal drilling of the cart. This procedure will spool the thread inside of the cart and therefore lift the weight holder.
- The light barrier interruption times Δt_i have been used to determine the instantaneous velocities of the cart. However, the cart is still accelerating during the interruption process so the calculated instantaneous velocities actually represent the mean velocity during that period. Considering that fact, minor deviations in a range of up to a few percent from the theoretical values can be explained.
- If the height of the table is not sufficent to accelerate the cart across the entire track, it is possible to double the distance by use of movable pulley as shown in the figure. The guidance bracket that comes along with the holder for pulley has to be attached to the screws, as well. Then, the end of the silk thread must not be fixed to the weight holder but to the bracket, instead. The movable pulley is placed on top of the thread and, finally, the weight holder including the adjustable slotted weights is mounted to the hook of the movable pulley
- The entire experiment solely treats one-dimensional motion thus as simplification, the dependency on the direction has been neglected. Generally, one must consider that force, acceleration, velocity, and displacement are vectors.

CALCULATIONS

M_{sw}	M+m in kg	t_1 in s	$\Delta t_1\ in\ s$	t_2 in s	$\Delta t_2\ in\ s$	1/(M+m) in kg	a_m in m/s^2

m in kg	t_1 in s	$\Delta t_1\ in\ s$	t_2 in s	$\Delta t_2\ in\ s$	$\Delta t_2\ in\ s$	$F_G = m.g$ in kg.m/s^2	a_m in m/s^2