Verification of the Newton’s 2nd Law of Motion

Tuesday, 1st March, 2022

PH1102: Physics Lab I

Newton's Second Law

The force $\mathbf{F}$ required to move a body of given mass with an acceleration $\mathbf{a}$ is proportional to the acceleration $\mathbf{a} \Rightarrow \mathbf{F} \propto \mathbf{a}$

The force $\mathbf{F}$ required to move a body of mass m with a given acceleration $\mathbf{a}$ is proportional to the mass $m \Rightarrow \mathbf{F} \propto m$

$$\mathbf{F} \propto m\,\mathbf{a} \qquad \Rightarrow \qquad \mathbf{F} = \mathrm{K}\, m\,\mathbf{a}$$

We choose the unit and dimension for force such that K is unit and dimensionless.

$$\mathbf{F} = m\,\mathbf{a}$$

Action System Response

The System m

The body to be moved under the influence of the applied force is called system here and it is described by it mass m.

Lab: In the laboratory experiments it is tuned by loading the *slider* with different weights

The Action $\mathbf{F}$

We generate and control the acting force $\mathbf{F}$ by means of the second law of motion itself.

We use some weight and hang it from a string. The generated force is proportional to the constant acceleration due to gravity and the mass of the hanging weight.

We control the generated force by changing the hanging weight.

The Response $\mathbf{a}$

The response $\mathbf{a}$ is to be measured. And all the experimental setup and post processing of the data is designed to estimate the acceleration $\mathbf{a}$ of the body under a chosen set of experimental conditions.

This is done by measuring position as a function of time.

Lab: In laboratory, the position is measured at regular interval by a camera

Experimental Setup and Data analysis

Setup: The hanging weight is connected (by a string) to a movable setup (cart or slider) on an almost frictionless horizontal surface

Laboratory

For the laboratory experiment, the experimental setup, execution, data collection and the analysis will be demonstrated in a prerecorded video.

Simulation

For the online experiment, the experimental setup, execution, data collection and the analysis will be demonstrated live during the class.

Working Formula

Let T be the tension in the string connecting slider and the hanging weights:

For the (vertical) motion of the hanging weight m $T = mg - ma$

For the (horizontal) motion of the system M $T = Ma + \mu Mg$

Here g is acceleration due to gravity and μ is coefficient of friction.

$$a = (mg - \mu Mg)/(m+M) = g\,(m - \mu M)/(m+M)$$

For μ=0, we have $a = mg/(m+M)$, i.e $a \propto F$ and $a \propto 1/(m+M)$

In the experiment, we try to minimize the friction by using air track and use $(m+M)$ as the mass of the system that moves.

Laboratory Demonstration Video

Dr. Rumi De

Data Processing : Fixed mass case

1. Look at the x vs t data for fixed mass case. Plot x vs t plot.
2. Using mid-point derivative, compute v vs t and plot.
3. Using finite difference formula, compute a vs t and plot.
4. Using fitting to c + v*t + a*t^2/2 obtain acceleration a for each case.
5. Plot Force (=mg) vs fitted acceleration and obtain a linear fit.

v(t+dt/2) = [x(t+dt) - x(t)]/dt

a(t) = [x(t+dt) + x(t-dt) - 2 x(t)]/dt^2

Data Processing : Fixed force case

1. Look at the x vs t data for fixed force case. Plot x vs t plot.
2. Using mid-point derivative, compute v vs t and plot.
3. Using finite difference formula, compute a vs t and plot.
4. Using fitting to c + v*t + a*t^2/2 obtain acceleration a for each case.
5. Plot total mass vs fitted inverse acceleration and obtain a linear fit.

v(t+dt/2) = [x(t+dt) - x(t)]/dt

a(t) = [x(t+dt) + x(t-dt) - 2 x(t)]/dt^2

Analysis and Plots

1. Plot force vs acceleration in the fixed mass case.
2. Plot mass vs inverse acceleration in the fixed force case.