86. Damping and Friction Coefficients

I. Introduction

One of the most fundamental concepts in physics is energy conservation. Its definition in classical mechanics states that the total energy of a closed system (i.e. a system that doesn't exchange neither energy or matter with the external world) must be conserved. From everyday life, however, several examples can be found where this principle seems to be violated, among them the most common are the phenomena of damping and friction.

Damping In Newtonian physics, an *inelastic collision* is defined as a collision event where the total momentum of two or more objects colliding is conserved, but not their energy. The lost energy can be transformed either into heat (therefore increasing the temperature of the two bodies) or it can lead to the deformation of one of the two. If one of the two objects is easy to deform, it is said to introduce a *damping* in the motion of the other one.

Friction Another well known phenomenon leading to energy loss in a system is friction. The friction force F_f between solids is the force exerted by a surface to oppose the movement of a body across it. The direction of the friction force is always perpendicular to the normal force N between the two solids.

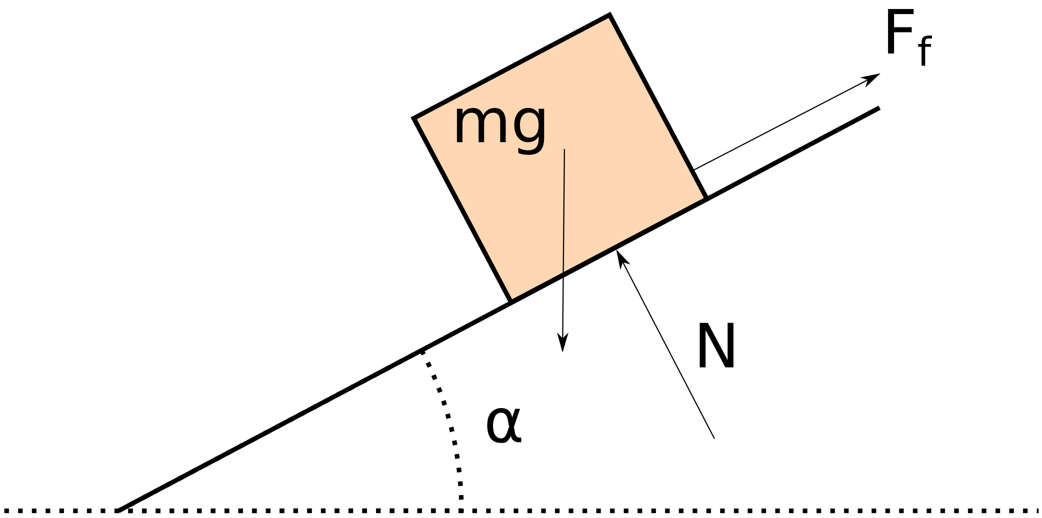

Figure 1: Friction force F_f and gravity

The magnitude and behaviour of F_f strongly depends on the relative movement between the bodies. We can distinguish between two different types of friction:

- Static friction, i.e. the force a body has to overcome to be able to start moving. The friction force F_s is equal to the force trying to get the body to move, up to a maximum value
$$F_s \leq \mu_\mathrm{s} N \tag{1}$$
where μ_s is referred to as the coefficient of static friction.

- Dynamic friction, i.e. the friction force present where there is a relative velocity between the solids, for instance one is sliding over the other one. In this case the friction force is constant:
$$F_k = \mu_\mathrm{k} N \tag{2}$$
where μ_k is referred to as coefficient of dynamic friction.

Requirements for the experiment

- Smartphone and app Phyphox for data collection.
- Computer for data recording and analysis. The Phyphox app can be accessed from your computer if phone and PC are connected over the same network (e.g. home WiFi or personal hotspot, check the app's website for help).
- A bouncing ball, e.g. a basketball or ping pong ball.
- Stackable damping material: paper.
- Large, flat, and tiltable surface, e.g. a kitchen chopping board.
- Collection of objects of different materials: a carton box, food cans, metal box, plastic lunch box...

II. Tasks

1. Damping measurement

- Estimate the percentage of energy lost in every bounce of the ball.
- Estimate the additional damping introduced by each additional layer of damping material.
- Extrapolate the behaviour of the system when more damping layers are added.

2. Friction coefficient measurements

- By varying the inclination angle, study the static friction coefficient between the two materials and compare it with literature values.
- Repeat the same measurement by increasing the weight of the object and observe if and how the coefficient of static friction evolves.

III. Experimental Setup

1. Task 1

The study of the energy loss of a bouncing ball can be performed with the Phyphox tool *Inelastic Collision*. The app lets you record the time gap between consecutive bounces and obtain an estimate of the energy retained after each bounce. Please read the online manual and check the video instructions beforehand.

The goal of this task is two-fold:

1. Calculate the relative energy loss E_{loss} per bounce under different conditions. To accurately control the damping, the number of layers n_{L} of stacked paper foils is used. E_{loss} should be calculated and plotted for $n_{\mathrm{L}} = \{0; 1; 2; 3\}$. Assuming a linear dependence of E_{loss} with n_{L}, it is possible to calculate the damping coefficient γ from the relation $E_{\mathrm{loss}} = \gamma n_{\mathrm{L}} + E_{\mathrm{loss},0}$, where $E_{\mathrm{loss},0}$ is a constant.
2. Predict the relative energy loss for $n_{\mathrm{L}} = 4$ and $n_{\mathrm{L}} = 5$, and validate the predictions.

Note. In order to obtain an accurate value of the energy loss E_{loss} for each different number of layers n_{L}, the measurement should be repeated multiple times and the values averaged. Their standard deviation can be taken as a measurement of the experimental uncertainty of E_{loss} for each value of n_{L}.

2. Task 2

The study of the friction coefficients can be performed with the Phyphox tool *Inclination*. The app lets you record several relative inclination of the phone; in particular we will use the *plane* option which measures the inclination of the plane where the phone is resting.

Figure 2 shows the experimental setup using a kitchen chopping board as rest plane. The phone lays flat on the board and will measure its inclination angle α with respect to the ground. As α is increased, so does the frictional force F_f until the final value $F_s = \mu_s N$ is reached. Then the body will start sliding and the static frictional force no longer applies. By recording the angle at which the static frictional force is overcome, μ_s can be calculated.

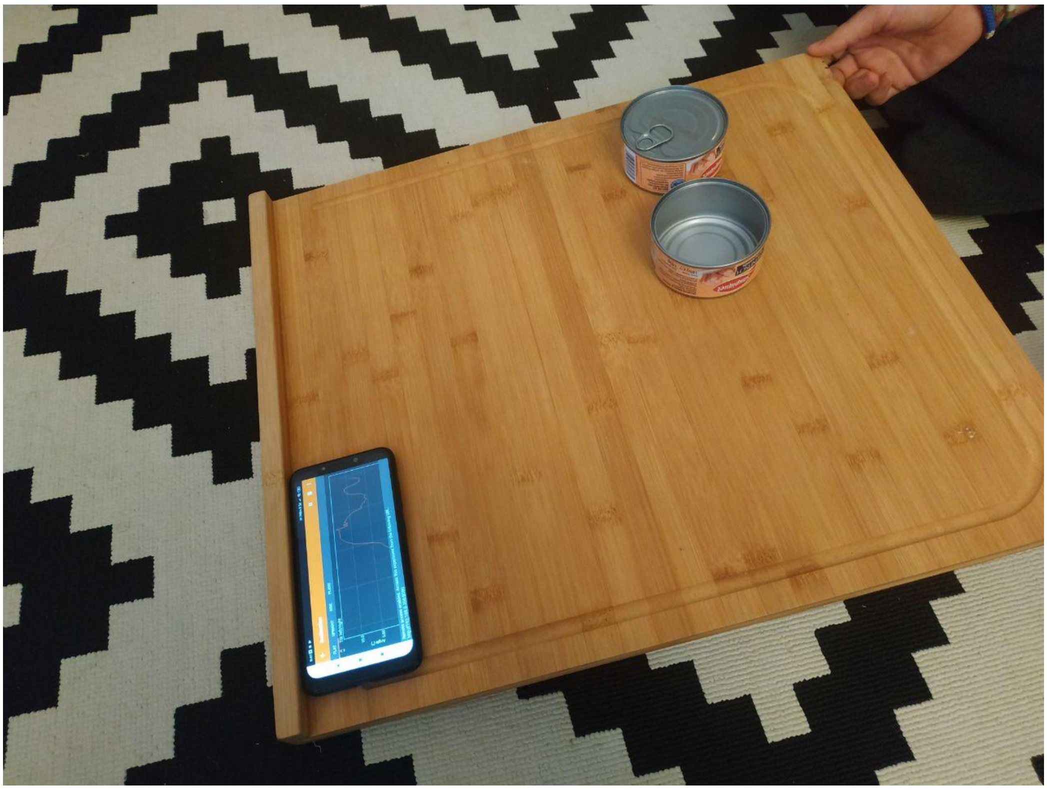

Figure 2: Setup to measure the friction coefficient

The goal of the experiment is to find out the coefficient of static friction μ_s for different material combinations (for example metal on wood, plastic on wood, paper on wood, plastic on plastic, etc.) and compare them with the literature. The relation between the inclination angle α and the coefficient of static friction μ_s can be easily retrieved from the forces at equilibrium when the object starts to slide. Also in this case, in order to obtain a more accurate result, the measurement should be repeated several times.

Lastly, it is interesting to look qualitatively at if and how the coefficient of static friction μ_s changes when the weight of the object sliding increases (for example, when piling more objects on top of each other).

Sample Report

General goal: allow a person, who is not familiar with the topic, to reconstruct and reproduce exactly the experiment you have performed.

Contents:

- Description of the experimental procedure and short insight of the physics behind it (what are friction and energy loss, what approximations the app makes, how you have collected the data, etc).
- Results (individual measurements, mean and standard deviation):
  - Energy loss for different damping layers.
  - Measured angles for different materials.
- Graphs: energy loss vs. number of damping layers, with units, labels and error bars.
- Values with experimental errors and detailed error propagation:
  - Damping coefficient γ.
  - Friction coefficient μ_{s}.
- Discussion of the obtained results:
  - Validity of measurements.
  - Comparison with literature values (with references) for the different friction coefficients.
  - Influence of increasing object mass on the friction coefficient.
  - Main sources of uncertainties and systematic errors.

Note: More info on error propagation. As for the literature values of the various friction coefficients, you find very useful links in the references of the friction coefficient Wikipedia page.