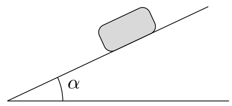
1^{st} Physics exam – Semester 1
October 21, 2022. Duration: 1 h.

No document allowed. No mobile phone. Non-programmable calculator allowed. The proposed grading scale is only indicative.
The marks will account not only for the results, but also for the justifications, and the way you analyze the results. Moreover, any result must be given in its literal form involving only the data given in the text. It is also reminded that the general clarity and cleanness of your paper may also be taken into account.

Exercise 1: Determination of a static friction coefficient $[\sim 12\,$pts.$]$

In mechanics, the static friction coefficient μ_S is defined as the ratio between the magnitudes of tangential $\vec{R}_T$ and normal $\vec{R}_N$ components of the reaction force exerted by the support: $\mu_S = \frac{\|\vec{R_T}\|}{\|\vec{R_N}\|}$. Several experimental methods can be used to determine the friction coefficient between two solids. The goal of this exercise is to compare the results of two methods.

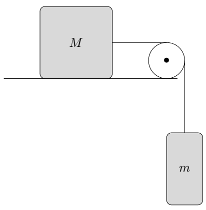
1. **Method 1: Measure of the critical angle**
   A simple method consists in i) placing a cube made of material 1 on a board made of material 2 and ii) lifting one extremity of the board. The critical angle α is the angle between the board and the horizontal axis, for which the cube starts moving (see adjacent figure).

   You will soon show in your mechanics course that the static friction coefficient μ_S is related to the critical angle α through
   $$\tan(\alpha) = \mu_S.$$
   The experiment is carried out for a wooden cube on a wooden board. A picture is provided in figure 1 at the critical angle.

   (a) How can you determine the experimental value of $\tan(\alpha)$ without a protractor?
   (b) List all the sources of uncertainties on direct measures, and estimate their contributions. You can present this as an Ishikawa (5M) diagram.
   (c) Write each direct measure along with its uncertainty. Indicate on figure 1 the physical quantities you measured.
   (d) Finally, determine the value of the static friction coefficient μ_S along with its uncertainty.

2. **Method 2: Change the mass of the tested body**
   A second method is presented schematically in the adjacent figure. The cube of material 1 and mass M is placed on the board of material 2. Using a string going through a pulley, we pull on the cube by hanging an object of mass m to the extremity of the vertical string. We then note the value of mass m that is necessary to start moving the cube of mass M.

   You will soon show in your mechanics course that mass m is proportional to M, the proportionality coefficient being precisely the static friction coefficient:
   $$m = \mu_s M.$$
   In an experiment, we vary the cube mass M and measure the values of m that initiate the movement of the cube. Masses are known with an uncertainty of 5%. Experimental data is presented in the graph of figure 2.

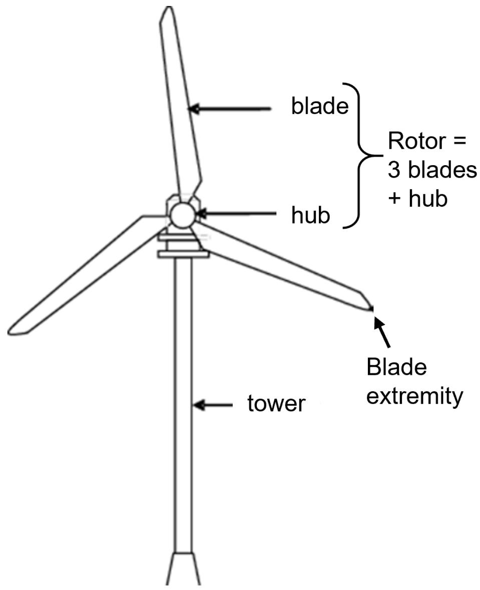
   Using a graphical method, determine the static friction coefficient, along with its uncertainty.

3. Compare both methods and conclude.

Exercise 2 : Study of a wind turbine [~ 8 pts.]

In this exercise we study some features of a wind turbine. Under wind, the rotor, made of 3 blades and a hub (see figure), starts rotating. This movement induces the rotation of an alternator that generates an alternate electric current. The moving elements are subjected to friction forces heating the system. Some data that may - or may not - be useful for the exercise are provided in the table below.

Vestas V90-3.0 Onshore or offshore wind turbine First commissioning 2002	
Number of blades Rotor diameter Height of the hub	3 90,0 m 80 or 105 m
Rotor mass	41,0 t
Nominal power of the wind turbine	3 MW
Mechanical efficiency	60 %
Total efficiency	35 %
Wind velocity leading to wind turbine start-up	$4.0\,m\cdot s^{-1}$
Wind velocity corresponding to wind turbine nominal power	$15.0\,m\cdot s^{-1}$
Wind velocity leading to wind turbine safety stop (risk of failure)	$25.0\,m\cdot s^{-1}$
Dry air mass density at atmospheric pressure at sea level and temperature of 15°C (standard used in wind turbine industry)	$1.225\,kg\cdot m^{-3}$



1. What is the “total efficiency”? and the “mechanical efficiency”? Discuss briefly these values and provide possible explanations.

2. Knowing that the power P delivered by a wind turbine depends on the air mass density ρ, the wind speed v and the blades length ℓ, determine by dimensional analysis an expression of P as a function of these quantities (you can introduce a dimensionless coefficient k).

3. The horsepower (HP) is a power unit that corresponds to the power developed for lifting a mass m = 550 lb at a velocity v of 1 $ft\cdot s^{-1}$. It is defined as $P = mgv$, where $g = 9.81\ m\cdot s^{-2}$ is the standard gravity. What is the power in nominal working conditions, expressed in horsepowers? We recall that 1 ft = 30.48 cm and 1 lb = 453.6 g.

NAME : ....

To be returned with your paper!

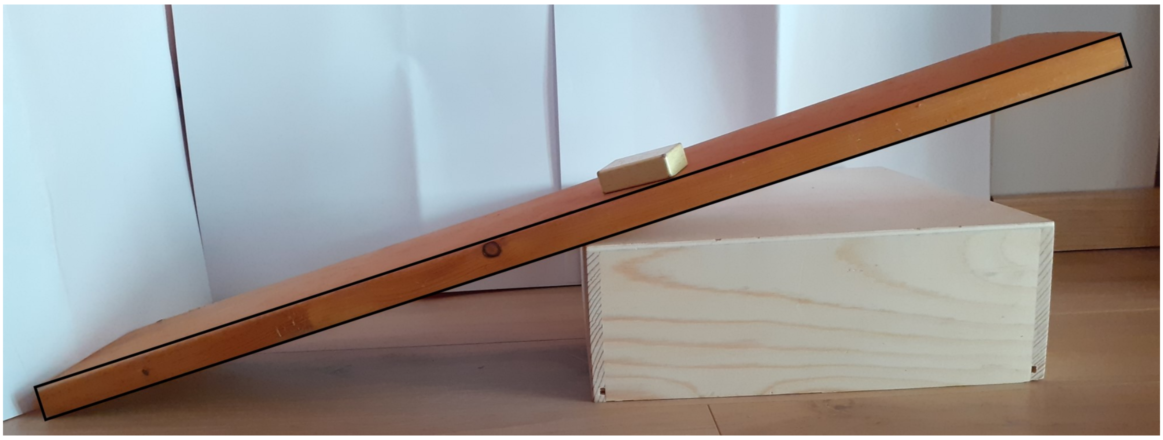


Figure 1: Method 1: Picture of the experiment at the critical angle. The borders of the board have been highlighted for better visibility

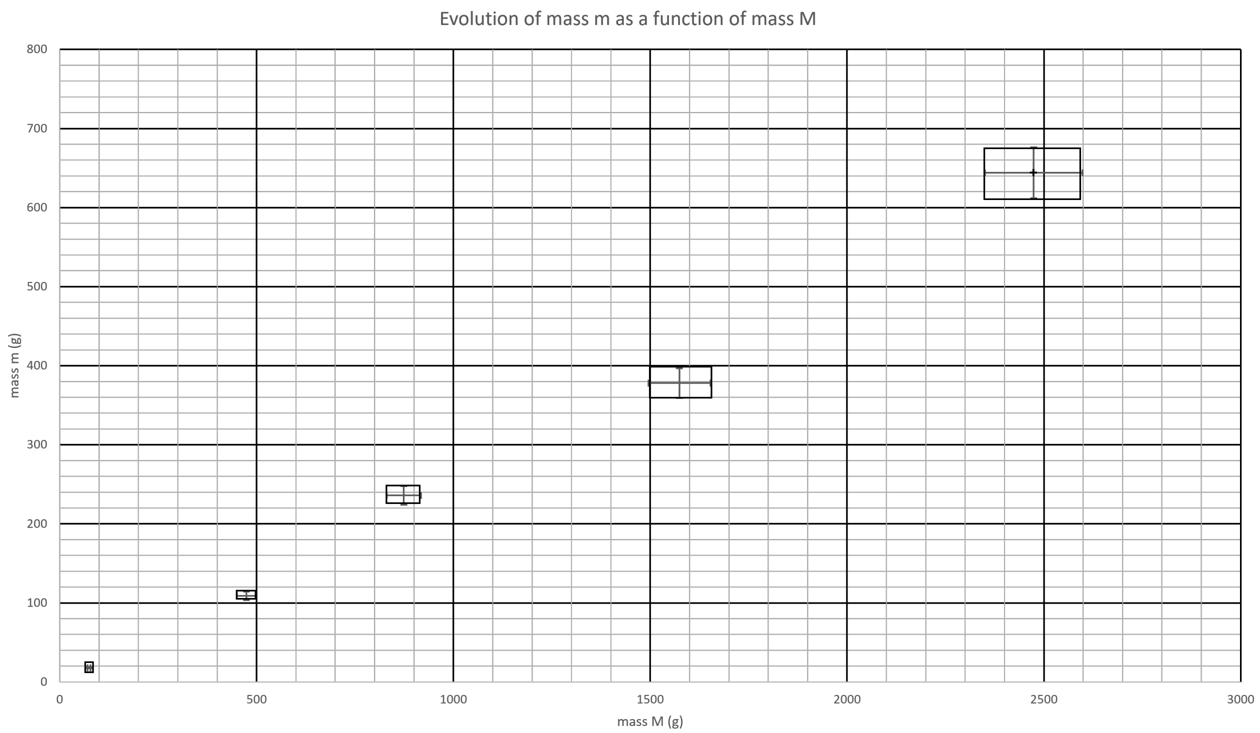


Figure 2: Method 2: Graph representing: $m = f(M)$