الجمـــهورية الجزائريــــة الديمقراطيــــة الشعبيــــة

DEMOCRATIC AND POPULAR REPUBLIC OF ALGERIA

Ministry of Higher Education and Scientific Research

University 8 May 1945 Guelma

Faculty of Mathematics and Computer Science and Sciences of matter

Department of Science of Matter

وزارة التعليـم العالــي والبحث العلمـي

جامعة 8 مـــاي 1945 قالمــة

كليــة الرياضيـات والإعـلام الآلـي وعلــوم المـادة

قسم علــوم المـادة

Polycopy of Practical Work

Physical 1
Point mechanics

Appointed to the departments:
Science of Matter and Science and Technology.

1st Year L.M.D

Presented by: Dr. Rafik MAIZI

Academic year 2024/2025

University of 8 May 1945 Guelma
Faculty of Engineering
Department of ST or SM (LMD)

First Year
TP Physics 1

Debrief n°…………

TP title:……………………………………………..

Presented by
Name :

First Name :

Group :

Sub-group:

Led by

Note and Comments

/20

Academic Year 2024

University 8 May 1945 Guelma *Year 2024*

Faculty of Mathematics and Computer Science and

Sciences of Matter

Sciences of Matter Department

1st Year Bachelor

Practical Work

of

Point Mechanics (Physics 1)

Table of contents**:**

The steps to write a report

1) Introduction
2) Theoretical study
3) Purpose of the manipulation
4) Materials used
5) Assembly diagrams
6) Value tables
7) Graph tracing
8) Error calculations
9) Comparisons and Interpretations
10) Conclusion

Carried Out By
Dr. MAIZI Rafik

الجمهورية الجزائرية الديمقراطية الشعبية

وزارة التعليم العالي والبحث العلمي

برنامج البيداغوجي

للتعليم القاعدي المشترك
السنة الأولى

ميدان

علوم المادة

30 avril 2018

UE : Méthodologie
Matière : TP Mécanique

Objectifs de l'enseignement

- Consolidation des connaissances théoriques acquises en cours de Mécanique du point (Physique1) avec l'application du calcul d'erreurs.
- Apprentissage et visualisation des phénomènes liés à la Mécanique classique.

Connaissances préalables recommandées

- *Il est recommandé d'avoir bien maîtrisé les sciences physiques dans le cycle secondaire.*

Contenu de la matière :

1- Calculs d'erreurs
2- Vérification de la 2ème loi de Newton
3- Etude de pendule physique
4- Chute libre
5- Pendule simple
6- Pendule de Maxwell
7- Etude de la rotation d'un solide
8- Vérification de la fondamentale d'un mouvement circulaire – conservation de l'énergie mécanique

Mode d'évaluation :

Continu : 50%   Examen : 50%

Références*(Livres et polycopiés, sites internet, etc)* :

- T. HANNI, *Mécanique généralecours et exercices*, OPU (1996).
- J TAYLOR, *Incertitudes et analyse des erreurs dans les mesures physiques*, Dunod, Paris, (2000).
- H. LUMBROSO, *Mécanique du point*, 1ère an. MPSI - PCSI - PTSI - Problèmes résolus,
- F. FAGET, M. MAZZASCHI, *Mécanique du point, Exercices corrigés*, Ed. Dunod Paris, (1999)

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قسم علــوم المـادة

Department: Science of Matter

SYLLABUS

Teaching Unit: Fundamental Unit (UEF: Methodologies)

Subject: Practical Physics 1, one session per week

Field/ Stream/ Pathway: SM/ Physical

Semester: 1; Academic year: 2023-2024

Total weekly hourly volume: 3 hours

Practical work: «Number of hours per week»: 3 h

Language of instruction: French and English

The teacher responsible for the subject is Dr. Rafik Maizi. Grade: M.C.A

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Aims and goals

This TP aims to train first-year core students and deepen their knowledge in the practical field. It is geared toward first-year L.M.D. students. So you develop your ability to manipulate these ideas and apply them to concrete situations. In progressing through this TP, the student realizes how this program is based on general, basic principles and how they are applied to the understanding of a wide variety of physical and chemical phenomena.

The manuscript content corresponds to the official program of TP Physique 1st taught to first-year L.M.D. students of the S.M. and S.T. programs.

This handout contains five TPs and an appendix. Detailed TP's

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In the end, I hope that this subject will be a valuable tool and an important pedagogical support for the students. I wish you good luck and good luck.

Foreword

In this TP we propose to study the free fall movement, the principle of mechanical energy conservation by measuring the transformation of potential energy into kinetic energy of translation and rotation. By determining the moment of inertia of the Maxwell wheel. We will also study and differentiate between two shocks: elastic and soft. In fact, we will enforce Newton's laws. Finally, we will finish by calculating the moments of inertia of a metal rod and a disc.

Evaluation Modalities: The evaluation is based on the following weightings:

Debriefing report	50%	8 points
Participation during the TP « Assembly of circuits, manipulations, and questions »	10%	1.5 points
Defense $\Leftrightarrow \begin{cases} Oral \\ \text{written} \\ Oral \text{ and Written} \end{cases}$	40%	6.5 points
Final score	100%	16/20

Attendance is mandatory, and the maximum score is **16**/20.

TP Manager **Dr. MAIZI R**

TP Physics 1

Foreword

All sciences are based on the confrontation between the results of supposedly representative experiments and theories supposed to objectively describe the reality of the world. Both approaches, experimental or theoretical, are naturally accompanied by the notion of doubt, which is a fundamental concept for a future engineer.

This handout gives some basic clues so that the experimenter can present his results with common sense.

The objective of the practical work is to determine whether a theory or a law is valid or not, we compare it to our experimental measurements. For this, it is essential to be able to accurately estimate uncertainty. So, the uncertainty associated with an experimental measurement that can be as important as the result of the measurement itself!

TP N°01: Uncertainty calculations

1. Types of errors in the experimental data

There are three main types of errors:

a) Random errors affect measurement accuracy. They are studied either by performing uncertainty calculations or by statistically comparing the results of carefully repeated experiments.

b) Coarse errors rarely occur and are easily identified as they lead to eccentric values that differ significantly from the results of a series of measurements. They are naturally eliminated before the results are interpreted.

c) It is much more difficult to identify systematic errors that affect accuracy. For example, a systematic error has obviously crept into the chromatographic method. It is difficult to be exhaustive in describing systematic errors. The main ones are:

- The errors of method.
- Instrumental errors: An analog-to-digital converter can be poorly calibrated.
- Personal errors: Systematic errors are the most difficult to detect and require constant vigilance in laboratories.

2. Absolute and relative uncertainty

An experimental measure is always affected by uncertainty, regardless of the quality of the material and the talent of the experimenter.

2.1. Calculation of absolute uncertainty (Δf)

The differential of f(x, y) is written as a function of the partial derivatives with respect to each of the variables x, y. This is limited to two variables: $df = \frac{\partial f}{\partial x} dx + \frac{\partial f}{\partial y} dy$

Then we approach $df \cong \Delta f$, $dx \cong \Delta x$ et $dy \cong \Delta y$

We obtain: $\Delta f = \frac{\partial f}{\partial x} \Delta x + \frac{\partial f}{\partial y} \Delta y$

2.2.Calculation of relative uncertainty $\frac{\Delta f}{f}$

To calculate relative uncertainty, the logarithmic differential method is used

Arithmetic mean value $d(\ln f) = \frac{df}{f}$

For all measured values $(x_1, ..., x_n)$ we define its arithmetic mean by the formula:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

The final result is expressed in the form of an interval of probable values $x_f = x_m \pm \Delta x$, knowing Δx that is the uncertainty on the measure that one seeks to evaluate.

o **Standard deviation**

The standard deviation s of a series of n measurements is given by the following formula:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{(n-1)}}$$

, where are the results of the different measurements and $\bar{x}$ is the arithmetic mean of the n results considered.

Presentation of results:

In the final presentation of a result it is important to match the number of significant figures to the determined precision. In the case where an uncertainty is not explicitly given, scientists admit the level of the last significant figure as an order of magnitude of the uncertainty.

Example:

A = 23.0 units. You interpret A to be known within 0.1 unit.

B = 0.007 unit. You interpret that B is known to within 0.001 unit.

For the TP of Physics 2

o Definition of the class:

The class is defined as a percentage of the minimum scale of the instrument.

The class therefore, corresponds to an upper limit of absolute uncertainty quantified in number divisions of the scale. The device is more accurate when the class is lower.

Example:

A Class C = 2 device with a maximum division of 150 div is such that throughout the scale, absolute uncertainties remain below or at most equal to $\frac{2}{100}150 = 3div$.

o **Definition of absolute uncertainty:**

Absolute uncertainty is defined as: $\frac{Calibre \times Classe}{100}$

Example:

It is assumed that with an ammeter of class 1.5 one measures I = 20 mA on the gauge 100 mA, he comes $\Delta I = 1.5\frac{100}{100} = 1.5mA$

o Definition of relative uncertainty:

This is the relationship between absolute uncertainty and the measured value.

<u>N.B.:</u> In order to have the relatively low possible uncertainty, it is useful to measure with a maximum deviation on the scale of the device.

Example:

With a voltmeter of class 1.5 one wants to measure a voltage V of approximately 10 V.

Let V_1 measure on the gauge 15 V and V2 on the gauge 450 V.

$$\Delta V_1 = 1.5\frac{15}{100} = 0.2V \rightarrow \frac{\Delta V_1}{V} = \frac{0.2}{10} \cong 2/100$$

$$\Delta V_2 = 1.5\frac{450}{100} = 6.7V \rightarrow \frac{\Delta V_2}{V} = \frac{6.7}{10} \cong 70/100$$

TP N° 02 : Verification of Newton's 2nd Law

I) **Purpose of Handling**:

1. The purpose is the determination for uniformly accelerated straight motion
2. The path travelled over time.
3. Speed versus time.
4. Acceleration as a function of body mass.
5. Acceleration as a function of applied force.

In the first law, an object will not change its motion unless a force acts on it. In the second law, the force on an object is equal to its mass times its acceleration. In the third law, when two objects interact, they apply forces to each other of equal magnitude and opposite direction.

II) Procedure:

The hook is used to receive the silk thread and it is plugged on the trolley. To launch and to balance the masses, the magnet is fixed to hold on the other side of the trolley. The silk thread connects the trolley with the weight carrier using the precision pulley. The launching device is used to mechanically release the trolley and start the meter, see figure 1.

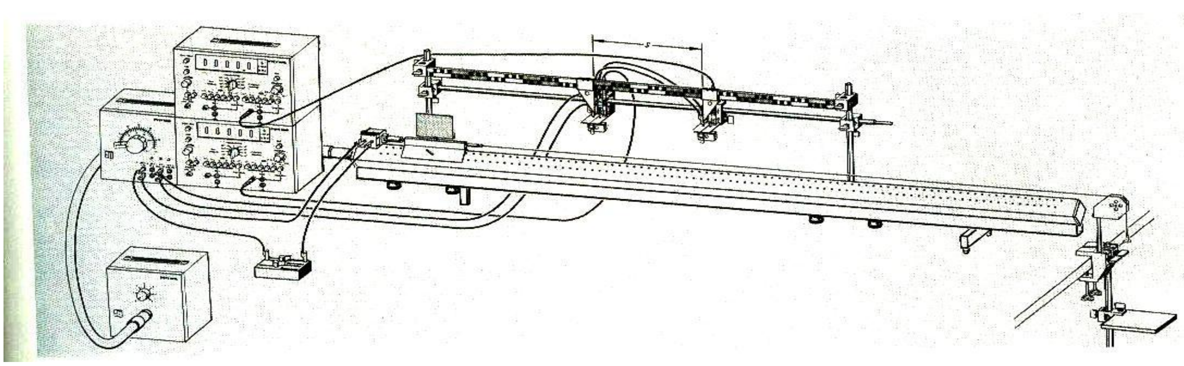


Figure 1: Assembly of NEWTON laws

III) Theoretical basis:

The Newton equation of the motion of a material point of mass m under force **F** is expressed as: $\vec{F} = m\vec{a}$ where $\vec{a} = \frac{d\vec{v}}{dt}$ (3.1)

a: acceleration of movement, v: speed of movement.

Hence: $\frac{d\vec{v}}{dt} = \frac{\vec{F}}{m}$ whereas: $d\vec{v} = \frac{\vec{F}}{m}dt$, hence: $\vec{v} = \frac{\vec{F}}{m}t$, with $\vec{v}_0 = \vec{0}$

Similarly, we have: $\vec{v} = \frac{d\vec{r}}{dt}$, $\vec{r}$: where vector position of the material point.

$d\vec{r} = \vec{v}dt = \frac{\vec{F}}{m}tdt$ with $\vec{r}_0 = \vec{0}$, therefore: $\vec{r}(t) = \frac{\vec{F}}{2m}t^2$ (3.2)

In this case the movement is one-dimensional and the force is caused by the weight of the mass m_1 (motor mass). $\vec{F} = m_1\vec{g}$ (3.3)

If $\mathbf{m_2}$ is the mass of the trolley, the equation of movement is written: $(m_1 + m_2)\vec{a} = m_1\vec{g}$ (3.4)

The speed is given by: $\vec{v}(t) = \frac{m_1\vec{g}}{m_1 + m_2}t$ (3.5)

The path travelled is given by: $\vec{r}(t) = \frac{1}{2}\frac{m_1\vec{g}}{(m_1 + m_2)}t^2$ (3.6)

IV) Handling:

Manipulation 01: Determination of distance as a function of time **r = f (t).**

The trolley is released by the launching device that simultaneously triggers the meter, the latter will stop counting as soon as the screen worn by the trolley crosses the light barrier. It displays the journey time.

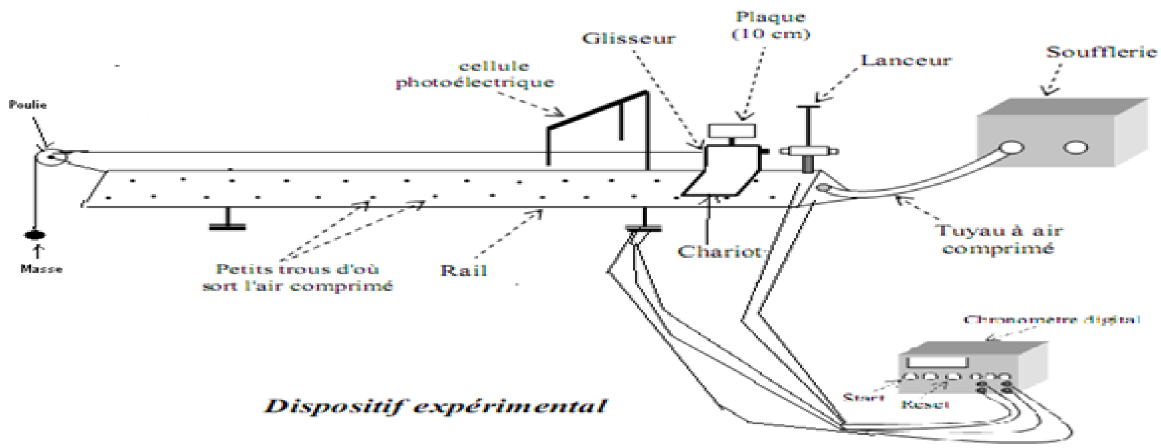


Figure 2: Operating Mode Instruments

i. Perform multiple tests for different distances.

ii. Complete the following table:

r cm)		30	40	50	60	70	80
t (s)	t_1						
	t_2						
	t_3						
t_{moy}(s)							
t^2 (s^2)							

iii. Plot the curve $\mathbf{r = f(t^2)}$. Interpret.

iv. Calculate ground acceleration g.

Handling 02:

Determination of speed as a function of time: speed – time. To determine the instantaneous speed, we must know the darkening time of the screen in the light barrier. This time is obtained most simply by measurement, once the STOP-INVERT button is pressed and the other time not pressed.

The time difference $\Delta \mathbf{t = t_2 - t_1}$ is the time of passage of the screen in front of the light beam « light barrier ». If Δ**S** is the length of the screen, you have: $V(t_1 + \frac{\Delta t}{2}) = \frac{\Delta S}{\Delta t}$ (3.7)

1) Run multiple tests

2) Complete the following table:

r(cm)	30	40	50	60	70	80
t_1 (s)						
t_2 (s)						
$\Delta t = t_2 - t_1$ (s)						
$t_{1+} \Delta t/2$ (s)						
$V = \Delta S/\Delta t$(cm/s)						

3) Plot curve $V(t_1 + \frac{\Delta t}{2})$. Interpret.

4) Conclude.

<u>Handling 03:</u>

- Determination of acceleration according to the mass of the trolley **a = f (m).**
- Successively increase the weight of the trolley by **20 g** (10 g on each side) and measure

time **t** in a fixed distance. Take **r = 60 cm**. $\vec{a} = \frac{m_1 \vec{g}}{(m_1 + m_2)}$

1. Complete the following table:

m (g)				
t (s)				
a (ms^{-2})				

2. Plot graph a=f (m), Interpret.
3. Calculate the uncertainty affected by the acceleration.

Manipulation 04: Determination of acceleration as a function of force " a = f (F)"

o Move successively **2 g** from the trolley (1g on each side) to the weight carrier and measure the time t in a fixed distance, knowing that $\mathbf{m_1}$ does not exceed 20g and the total mass of the system remains constant. Take **r = 60 cm.**

o Make several tests and determine for each case.

o Complete the following table:

m_1 (g)	10	12	16	18	20
F (N)=$m_1 g$					
t (s)					
a (ms^{-2})					

o Plot graph a = f (F). Interpret.

o Calculate earth acceleration g and its relative uncertainty **Δg/g**.

We give: $\vec{a} = \frac{m_1 \vec{g}}{(m_1 + m_2)}$, $\vec{g}_{exp} = \frac{(m_1 + m_2)}{m_1} \vec{a}$, $\vec{a} = \frac{2r}{t^2}$

TP N°03: Torsion Pendulum

Theory:

The torsion pendulum is composed of a solid moment of inertia **J** compared with the axis of rotation, moving around an axis consisting of a torsion spiral spring that is characterized by the constant **C**.

In the static case, a rotation of an angle θ corresponds to a force of value following the axis of rotation. **Γ = -C θ**

In the dynamic case of harmonic oscillations, we have the equation of motion $\frac{d^2\theta}{dt^2} + \frac{C}{I_z}\theta = 0$ and after its resolution, we find the period $T = 2\pi\sqrt{\frac{I_z}{C}}$

Operating procedure:

- To measure the torsion constant **C,** rotate the rod by a certain angle θ and measure the force F using the dynamometer.
- To measure the period, measure the half-period using the fork and the digital counter see **Figure 1**.

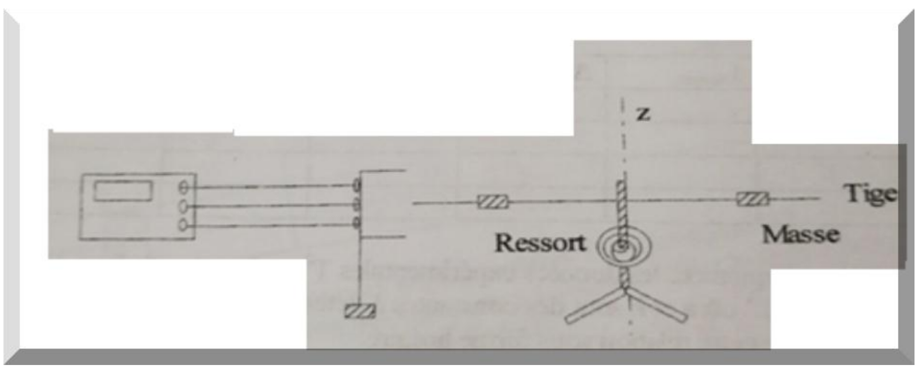


Figure 1: Setting up the experiment.

❖ **Determination of the torsion constant**

Two forces $\vec{F}_1$ and $\vec{F}_2$ form a couple to which the torsion torque of the wire is opposed. In balance, the torque of torsion **Cθ** compense therefore the torque created by the weight **P= m.g.**

❖ **Handling: measurement of the torsion constant**

◈To change the torque Γ, either we vary the masses **m**, or we vary the arms as shown in **Figure 2**.

◈Measure the angle of equilibrium θ_{eq} give the associated absolute uncertainty $\Delta\theta$.

◈Calculate the value of the torsion constant **C.**

Figure 2: Torsion constant calculation principle.

❖**Work required:**

⌖With the two masses symmetrically placed on the axis of rotation, measure the torsion constant of a spring for several angles θ of rotation.

⌖Summarize the results in a table

⌖Graphically represent Γ as a function of θ .

⌖Determine **C** by least squares method.

⌖Measure the period of oscillations and deduce the moment of inertia relative to the axis of rotation **Iz.**

⌖Theoretically calculate the value of **Iz**, compare this value with the measured value.

⌖Propose a technique to obtain the mass of the solid.

⌖Deduce the moment of inertia of the system.

Vibration diagram of a metal rod

TP N°04: Free Fall

I) **Purpose of Handling**:

- Determination of the relationship between fall height and fall time **h=f (t).**
- Determination of terrestrial acceleration g.

II) Procedure

We fix in the trigger an electrically conductive ball that closes the circuit of the starting current «STAT-INVERT push button pressed» see **figure 01**.

To determine the effective fall height with the trigger marking, the radius of the ball « r=1.9 cm » must be taken into account. The air resistance of the ball must be neglected.

III) **Theoretical basis**

The free fall of a body is the study of the movement of this body in the gravity field of module g. This movement is uniformly varied.

There are two free falls:

- Without initial speed
- With initial speed

That’s the first point we’re going to look at.

A body of mass m is accelerated from the resting position in a constant gravitational field. It performs linear motion. The coordinate system is arranged so that the y axis merges with the right of the motion and the corresponding one-dimensional equation of the motion is applied, see **Figure 1**.

The result is: $$m\frac{d^2}{dt}h(t) = mg \quad (1.1)$$

The solution to this differential equation is: $$h(t) = \frac{1}{2}gt^2 \quad (1.2)$$

With the following initial conditions: $h(0) = 0$ et $\frac{dh(0)}{dt} = 0$

VI) How to calculate the speed of a free fall

- Find the functional form of velocity versus time given the acceleration function.
- Find the functional form of position versus time given the velocity function.

The result is**: V= 2 g h** in m/s or ms^{-1}. The speed of a body in free fall does not depend on its mass but only on the acceleration of the field of gravity to which it is subjected, in the case of the earth: the field of terrestrial gravity **g**.

Example: we can estimate the depth of a vertical mine shaft by dropping a rock into it and listening for the rock to hit the bottom. But “falling,” in the context of free fall, does not necessarily imply the body is moving from a greater height to a lesser height.

Gravity

The most remarkable about falling objects is that if air resistance and friction are negligible, then in a given location all objects fall toward the center of Earth with the same constant acceleration, independent of their mass. This experimentally determined fact is unexpected because we are so accustomed to the effects of air resistance and friction that we expect light objects to fall slower than heavy ones. Until Galileo Galilei proved otherwise, people believed that a heavier object had a greater acceleration in a free fall. We now know this is not the case. In the absence of air resistance, heavy objects arrive at the ground at the same time as lighter objects when dropped from the same heigh.

V**) Free fall with muzzle velocity**

Gravity is the only force acting on an object in free fall. When one can neglect friction, the equation of free fall motion is simpler than that of the speed limit. $V(t) = V_0 + gt$

$V(t)$ is the speed at time t during free fall. **g** is acceleration due to gravity. **t** is the time since the beginning of the fall. V_0 is the initial velocity.

The acceleration of free-falling objects is therefore called acceleration due to gravity. Acceleration due to gravity is constant, which means we can apply the kinematic equations to any falling object where air resistance and friction are negligible. This opens up a broad range of interesting situations. Acceleration due to gravity is so important that its magnitude is given its own symbol, g. It is constant at any given location on Earth and has the average value**:** $g = 9.81\,(\mathrm{m/s^2})$

IV**) Work to be performed:**

1. Attach a ball to the trigger and mark each time the height h of the fall.
2. Turn on the interceptor switch and measure the time of fall.
3. Perform free fall **10** times for different heights.
4. Complete the following table:

h (cm)				
t (s)				
t^2 (s^2)				

5. Plot graphs h = f (t) and h = f (t^2).
6. Comment on both graphs.
7. Determine the Earth acceleration from the graph.
8. Calculate uncertainty on g knowing that: **Δh=1mm** and **Δt = 0.01S.**

IIV) Mounting the free fall:

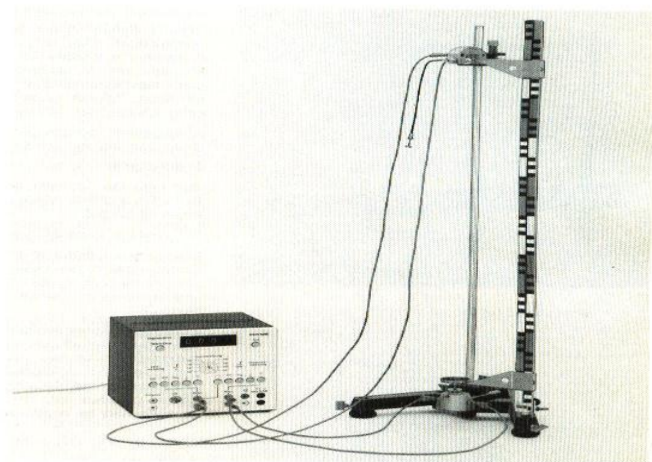


Figure 01: Free fall assembly

TP N° 05 : Simple Pendulum

Teaching objectives

The objectives assigned by this TP concern the initiation of students to put into practice the knowledge received on the phenomena of mechanical vibrations restricted to low amplitude oscillations as well as the propagation of mechanical waves.

Theory

A simple pendulum consists of a ball suspended from an inextensible wire attached to a support.

The total energy of the mechanical system is:

$$E = E_c + E_p$$

E_c is the kinetic energy, and Ep is the potential energy.

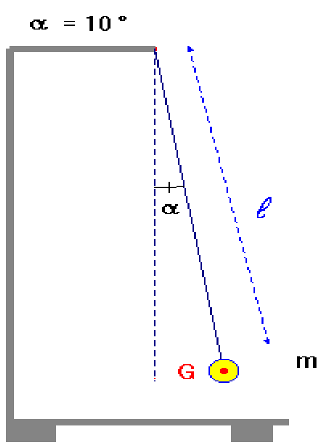


Figure 01: Simple Pendulum

With $E_c = \frac{1}{2} ml^2 \frac{d\theta}{dt}$ and $E_p = -mgl\cos\theta$,

after the combination, we will have: $\frac{1}{2} ml^2 \frac{d\theta}{dt} - mgl\cos\theta = E$

If **θ = θ₀** is the maximum angle, $\frac{d\theta}{dt} = 0 \quad E = -mg\cos\theta_0$

We obtain

$$\frac{d\theta}{dt} = \sqrt{2g\,\frac{(\cos\theta - \cos\theta_0)}{l}} \qquad \Rightarrow \qquad T = 4\sqrt{\frac{l}{2g}}\int_0^{\theta}\frac{d\theta}{\cos\theta - \cos\theta_0}$$

After development, we will have:

$$T = 2\pi\sqrt{\frac{l}{g}}(1 + \frac{1}{4}(\sin\tfrac{\theta_0}{2})^2 + ...)$$

For our case, we can write: $\sin\frac{\theta_0}{2} \cong \frac{\theta_0}{2}$

Applying the second order, **T** becomes as follows: $T = 2\pi\sqrt{\frac{l}{g}}(1 + \frac{\theta_0^2}{16})$

If $\boldsymbol{\theta_0}$ is very low; we obtain: $T = 2\pi\sqrt{\frac{l}{g}}$

Work required:

We can use the 4-decade counter with a light barrier for the measurement of half-period duration. Operating with the light barrier, the 4-decade meter is mounted in an electronic gate. Knowing that the length of the pendulum **L=l + r** , where **l** is the length of the wire and **r** is the radius of the ball, see **Figure 1**.

I- Measurement of the period T of the simple pendulum.

A) Procedure

A-1) Variation of T as a function of L

- Measure the half oscillation period at a low angle.
- Spread the ball and tension wire so that the angle **θ** between the wire and the vertical is about **10°**.
- Drop the object and let oscillate.
- Measure with a stopwatch the duration of the oscillation half-period $\frac{T}{2}$ (an oscillation corresponds to a round trip).
- Vary the length and repeat the operation.

- Deduce the value of the period **T**of pendulum then its frequency **f.**
- Fill out this table.

Table 1:

	L (length of pendulum)	ΔL	$\frac{T}{2}$	$T_{average}$	T^2	ΔT	Frequency f (Hz)
Measure 1							
Measure 2							
Measure 3							
Measure 4							

- Draw the curve giving the variations of $\mathbf{T^2}$as a function of **L** and conclude.

A-2) We can use $T = aL^b$, where **a** and **b** are constants.

- Write this relationship in linear form.
- Will determine **a** and **b** by the least squares method. (**a** is the value of the slope coefficient of the average line drawn.
- Deduct the value of **g**.

II- Influence of the starting angle:

Repeat the previous experiment with angles **θ** varying from **5°** to **15°.**

B) Procedure:

B-1) Variation of T as a function of amplitude θ

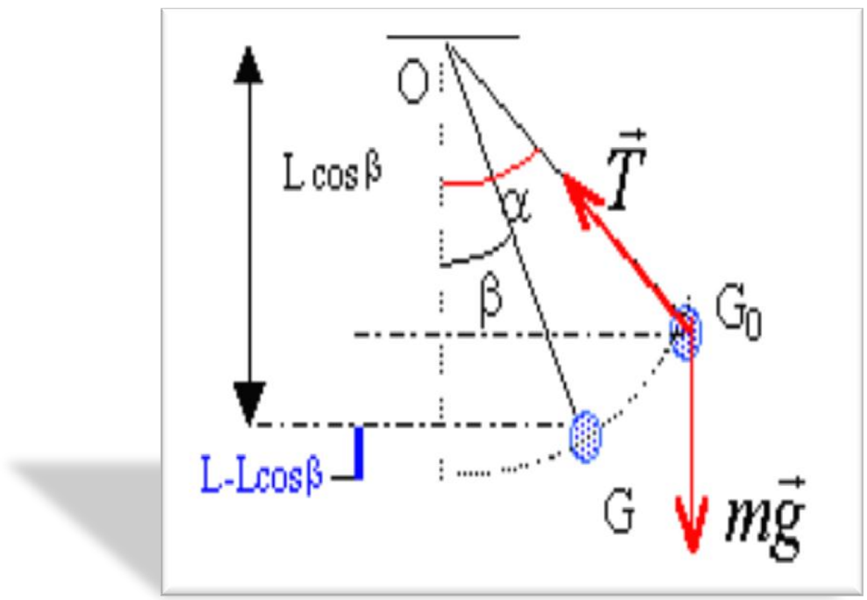
- Shorten the pendulum wire by approximately 20 cm.
- Vary **θ** and measure period **T**
- Repeat and complete the following table:

Table 2:

.

	θ	Δθ	$\sin^2(\theta/2)$	$\frac{T}{2}$	$T_{Average}$	ΔT	Frequency f (Hz)
Measure 1							
Measure 2							
Measure 3							
Measure 4							

- Plot **T** versus $\sin^2(\theta/2)$, where $T = a + b\sin^2(\theta/2)$. (Tracing on millimeter paper).
- Compare the values of the measured periods.
- What happens if the angle θ becomes too large?



Simple Pendulum Diagram

TP N° 06 : Maxwell Pendulum “Maxwell Wheel”

Principle of experience:

A ring or disc suspended by two strings that can unfold on its axis. It moves in a gravitational field. We are interested in the potential energy, the rotational translation kinetic energy and the mechanical energy they are determined as a function of time. Maxwell wheel demonstrates the conversion of kinetic energy into potential energy at high inertia moment.

Objectives:

• Determining the moment of inertia of a Maxwell Wheel.

• Determination of the potential energy, the kinetic energy of translation and that of rotation and transform each other into each other and they are determined as a function of time.

• Determination of angular velocity and angular acceleration.

• Calculation of acceleration using two experimental and theoretical methods.

Theoretical Background:

The Maxwell's wheel experiment investigates the conversion of potential energy, lineer and rotation kinetic energy, and their interaction with their environment. Physical facts can be classified as isolated or non-isolated systems, with total energy conserved in isolated systems. Energy can be found in various forms, such as mechanical, heat, nuclear, chemical, radiation, and electrical. In a hydropower plant, a water body rests at a certain height above tribunes, converting potential energy into kinetic energy. The Maxwell Wheel is an experimental setup to investigate these three energies: the potential energy, the energy of movement and the rotational energy A rigid metal disk is used, with a shaft passing through its middle axis and hanging from the ends by rope.

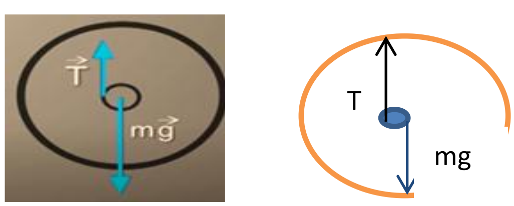
The disk starts to fall down, rotating around its own axis, and then rolls upward, avoiding friction. The Maxwell wheel is traditionally used to illustrate the notion of moment of inertia and the notions of kinetic energy of translation and rotation. It is a ring of large radius R and axis of small r, two strings are attached to the axis and fixed button, the strings can be wound on the axis of the ring, which released from the highest position, it rotates at the same time it goes down and up. It is much more than that of a free fall. Here is the diagram (figure 1) of the forces during the first descent. There is a T force by the rope on the axis.

The resulting acceleration is less than g. $a = \dfrac{(mg - T)}{m} \langle \text{ g}$

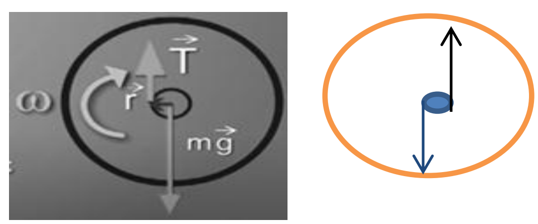
We see that the angular velocity increases when the ring goes down and it decreases when the ring goes up. During the descent, the ring that turns the clockwise direction is a vector that enters the plane of the diagram, the kinetic moment is a vector that is the direction and direction of **w**.

$\vec{L} = I\,\vec{w}$, we know that the variation of $\vec{L}$ due to the existence of a moment of force $\vec{\tau}$,

$\dfrac{d\vec{L}}{dt} = \vec{\tau}$



Descent Movement



Upward Movement

Here, it is the rope that exerts a moment of force, $\vec{\tau} = \vec{r} \wedge \vec{T}$ has the same meaning as $\vec{L}$, it enters the plane of the diagram. The moment of strength is responsible for an increase of $\vec{L}$ and therefore $\vec{w}$.

During the ascent, the ring continues to rotate in the same or horlogical direction. The moment of force is responsible for a decrease in the kinetic momentum $\vec{L}$ and also a decrease in the angular velocity $\vec{w}$.

From energy conservation, it can be written that the time of descent as a function of height h, radius of ring R and radius of axis as follows: $t_{descente} = \sqrt{\dfrac{2h(1 + R^2/r^2)}{g}}$

The moment of inertia of the ring I is a physical quantity that characterizes the geometry and the mass resistance of a solid in rotation. It is given by $I_{anneau} = mR^2$

Procedure set-up

Materials used:

- A so-called Maxwell wheel with a diameter D = 5mm, its mass m = 450g, moment of inertia I = 1.29 x 10-3 kg/m²
- Two wires (strings) inextensible.
- Digital stopwatch.

Figure 1: Maxwell Wheel Assembly Diagram

The two strings are turned inward so that the density of the windings is the same on both sides. The trigger is used to release the wheel and start the digital meter. The light barrier is used to measure time and stop the meter.

The instantaneous speed of the wheel is determined according to the time of obscuration of the axis of the wheel according to the relationship:

$$V(t + \frac{\Delta t}{2}) = \frac{\Delta s}{\Delta t} = \frac{D}{\Delta t} = \frac{D}{t_E}$$

Operation:

Mechanical energy consists of:

- The potential energy $\mathbf{E_p}$ of a physical system initially existing in the body and the energy related to an interaction to transform into kinetic energy. In our case, it will be expressed according to the relationship. $E_p = mgh$

- The kinetic energy $\mathbf{E_c}$ responsible for the movement displacement of the body. It corresponds to the passage between two positions "rest - final movement". Two kinetic energies are distinguished: translation according to the following relation: $E_{C(Tra)} = \frac{1}{2} m v^2$ and rotation according to the following relation: $E_{C(Rot)} = \frac{1}{2} I\, w^2$, where I represents the moment of the Inertia of the object rotating around an axis, and **ω** the angular velocity. For the isolated system the mechanical energy is constant.

$$E_{méc} = E_C + E_P = E_p + E_{C(Tra)} + E_{C(Rot)} = mgs + \frac{m}{2} v^2 + \frac{I}{2} w^2$$

With **ω** is the first derivative of time. Angular acceleration $\dot{w} = \ddot{\theta} = \frac{dw}{dt} = \frac{d^2\theta}{dt^2}$ is the variation of angular velocity over time. Thus, $\frac{ds}{dt} = w \wedge r$, r being the radius of the axis of rotation. In our case, g parallel with **s** and **ω** perpendicular to **r**, so that one has: $L_z = I_z w$

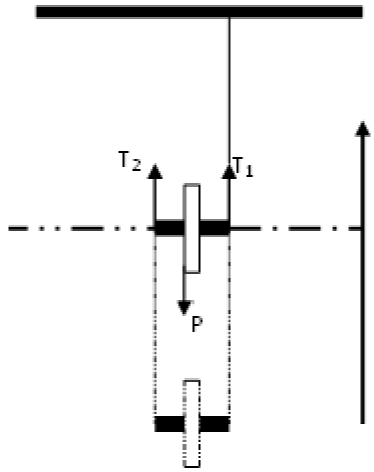
and $E = -m\, g\, s(t) + \frac{1}{2}(m + \frac{I_z}{r \times r})(v(t))^2$.

Exercise 01:

On one hand, we give the translation equation. P – 2T = ma, and on the other the rotation equation: $2T.R = I \frac{dw}{dt}$, T: wire tension force, ω = angular velocity

• Find the acceleration from the point to the center of gravity of the ring for non-slip movement.

Where m mass of the ring, I: moment of inertia of the ring, g: earth acceleration, R: radius of the ring. $a_{Théo} = \dfrac{mg}{m + \dfrac{I}{R^2}}$



Handling I (**Manipulation I):** Study of height h(t) or S(t) as a function of time for uniformly accelerated movement.

For different positions of the light barrier, h (figure above), the time of descent and the speed of translation must be measured and calculated using the counter S according to the following protocol.

I. Measurement of descent time, t, necessary to travel distance h

1. Connect the trigger to the **E** position of the counter.
2. Connect the light barrier to the F position of the counter. Select **MODE t_{EF}**
3. Move the wheel to the highest position and let it press the trigger (**Figure 2**).

4. Press **START.** Release the wheel (when the wheel starts moving, the meter starts measuring time.

5. After passing the wheel through the light beam of the barrier, the triggering system is pressed again and counting is interrupted.

6. Note down time, **t**.

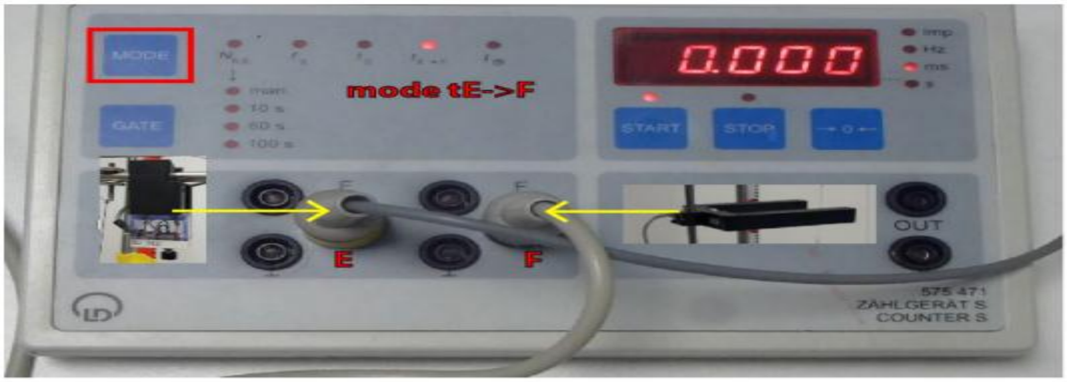


Figure 2: Height h(t) or S(t) as a function of time for uniformly accelerated movement.

Questions:

1. Perform several time measurements down $\mathbf{t_{E\text{-}F}}$ for different values of S(t) or h(t).
2. Complete this table

Number of measures	Height **h**(m) Or s(m)	Time t(s) t_1, t_2, t_3..	$t_{average}$ (s)	$t^2(s^2)$	a experimental $\frac{2h}{t^2}(ms^{-2})$	a theoric $\frac{mg}{m+\frac{I}{R^2}}$	$\frac{\Delta a}{a_{théo}}$
1							
2							
3							
4							

3. Plot **h** based on t and then based on $\mathbf{t^2}$.
4. Compare measured (experimental) and theoretical acceleration results.

Handling II: Study of instantaneous velocity V(t) as a function of time of uniformly accelerated motion.

II. Measurement of time Δt to calculate the translation speed V, at the light barrier

1. Connect the trigger to the **F** position of the Meter. Connect the light barrier to the **E** position of the meter.
2. Select $\mathbf{t_E}$ **MODE**.
3. Move the wheel to the highest position and let it press the trigger (**Figure 3**).

4. Press **START**

5. Release wheel (counter does not start measuring time)

5. When the wheel passes the light barrier the time **Δt** (i.e., the duration of obstruction of the light beam by the axis of the disc) is measured by the counter.

6. Note the obstruction time **Δt**.

7. The speed of translation (or instantaneous speed), **v**, is calculated according to the following equation : with the diameter of the disc axis, here, **d = 6 mm**.

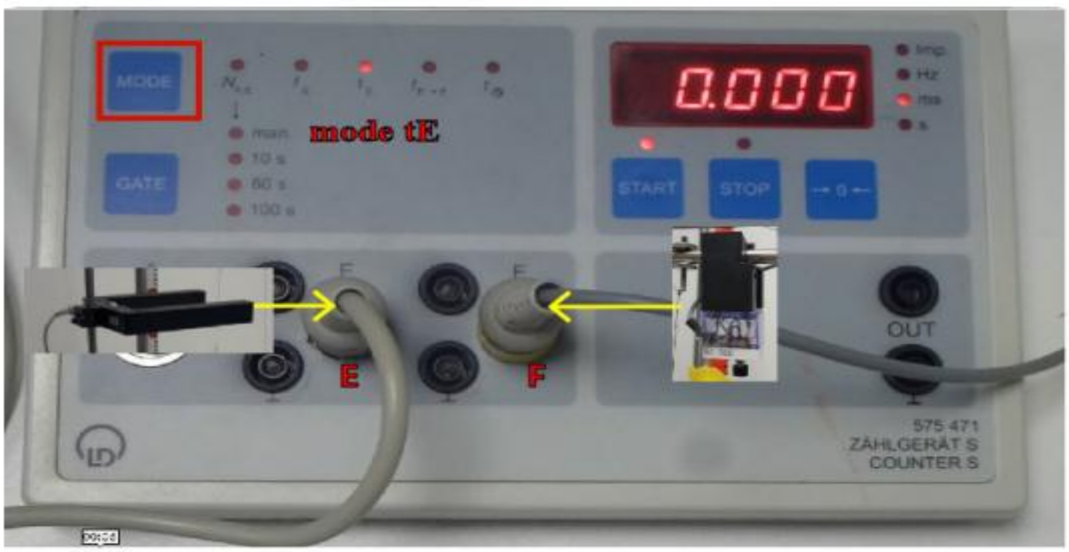


Figure 3: Measurement of time Δt to calculate the translation speed **V**, at the light barrier

Questions:

1) Measures the pass time $\mathbf{t_E}$ for different values of **S(t)** or **h(t).**

2) Complete this table.

Nombre de mesures	Height h(m) Or S(m)	Time (s), Δt_1, Δt_2, Δt_3..	$\Delta t_{average}$ (s)	$t^2(s^2)$	V(m/s)	$V^2(m/s)^2$	E_p (N.m)	$E_{c(Tra)}$ (N.m)	$E_{c(rot)}$ (N.m)
1									
2									
3									
4									

3) Plot V based on $(t+\frac{\Delta t}{2})$.

4) Trace E_p, $E_{c(Tra)}$ and $E_{c(Rot)}$ based on t.

5) Make a conclusion.

Exercise 2:

According to the principle of conservation of mechanical energy.

$$E_m = E_p + E_{c(Tra)} + E_{c(Rot)} = -m\,g\,S + \frac{m}{2}v^2 + \frac{I_z}{2}w^2 = Cte \;,$$

i. Determine the following S expression: $S(t) = \dfrac{\frac{g}{2}t^2}{(1+\frac{I_z}{m.r^2})}\, ou = \dfrac{\mathrm{mg}}{2(\mathrm{m}+\frac{\mathrm{I_z}}{\mathrm{r}^2})}t^2$ (1)

With **r**: radius of rotation axis

ii. Determine the expression of the moment of inertia from equation 1.

$$I_z = (\frac{gt^2}{2S(t)} - 1)\,\mathrm{m\,r}^2$$

TP N° 07: Study of the relationship of a solid "METAL ROD"

Objectives

- Determination of the value of the torsion constant **C** of metal rods of different characteristics.
- Determination of the eigenvalue of Coulomb **G** and Young **E** modules for each rod.

Theory:

A horizontal bar rotates around the axis of rotation via the rod. The centre of the bar is point **O**. When two forces $\vec{F}_1$ are applied to the terminal faces of a metal rod of length $\vec{F}_2$ and section **S** see **figure 1**. We observe a lengthening of the rod. Thus, **figure 2** shows the variation of the relative elongation according to the applied pressure, this variation is divided into three domains, the first domain of **0** to **L**, the second domain of **L** to **R**, where it is linear and reversible or the elastic limit and third upper domain of **R** which corresponds to the nonlinear and non-reversible variation, in other words, the force applied breaks the rod and does not return to its initial position. The deformation is called permanent, or we are in plasticity. (**L**: elastic limit, **R**: rupture).

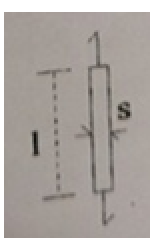


Figure 1: Applying two forces

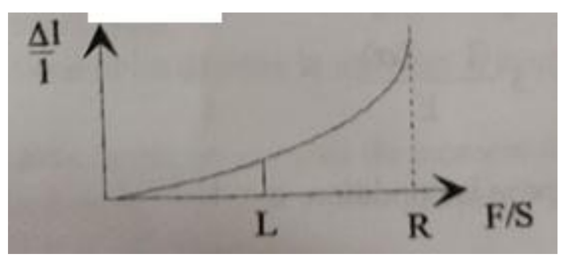


Figure 2: Change in relative elongation as a function of applied pressure.

The moment of inertia of the bar relative to the axis of the rod is $I_{barre} = \frac{1}{12} m_{barre}(l_{barre}^2 + a^2)$,

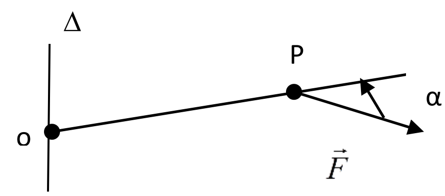
$\mathbf{l_{barre}}$: length of the bar and **a**: width of the bar.

I- Static study

We exert a constant force at a point **P** of one of the ends of the bar which will turn the system in a horizontal plane around center **O**. then, we move it away from an angle $\vec{F}$ to its equilibrium position which will impose a force of recall perpendicular to the bar to bring the system back to a stable state. In this case, the bar is subjected to two moments, one is the moment of force θ and the other is the moment of torsion exerted by $\vec{F}_R$.

To the balance, $\sum(moment\ \text{des forces})_{/\Delta} = 0$

We know that the moment $\vec{M}_{/\Delta} ou\ \Gamma$ of a force relative to an axis of rotation $\vec{F}$ according to the diagram opposite is $\Delta\vec{M}_{/\Delta} = \Gamma = \vec{F} \wedge \vec{OP} = F.OP\sin\alpha\ \vec{\text{u}}$



Thus, the moment of the return torque exerted is $\vec{M}_{/\Delta} = \Gamma = \text{-C}\theta$ with **C**: torsion constant of the rod, θ : angular displacement (deviation) from the equilibrium position.

a. Hooke’s Law:

The region of elasticity is expressed by the linear relationship: $\frac{\Delta l}{l} = \frac{\text{F}}{\text{E S}}$, **E** is called Young's modulus.

b. Lateral contraction:

During elongation, a narrowing occurs in the directions perpendicular to the support of the force. If there is a lateral dimension see **figure 3.** Knowing that the uncertainty on **d** is equal. $\frac{\Delta d}{d} = -\upsilon\frac{\Delta \text{l}}{\text{l}} = -\frac{\upsilon\,\text{F}}{\text{E S}}$

With υ is a positive number which is called the Poisson's Ratio.

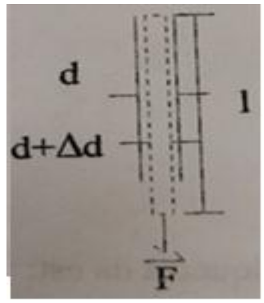


Figure 3: Narrowing (Shrinkage)

c. Compression:

The application of isotropic pressure results in a $\vec{P}$ variation of the volume **ΔV** from an initial volume **V** , the relationship between these quantities is: $\chi = -\frac{1}{P}\frac{\Delta V}{V}$ **(1)**

Where **χ** is the compressibility. To deduce the relationship between **E** and **χ,** we consider the parallelepiped subjected on all sides to a pressure **P** see **figure 4.**

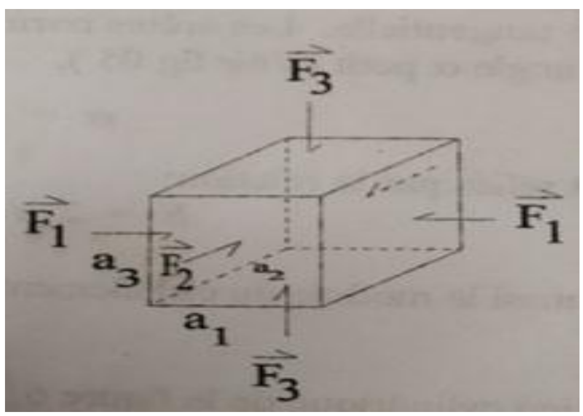


Figure 4: Parallelepiped under pressure **P**

$$\left\{\begin{array}{l}\frac{\Delta a}{a} = -\frac{1}{E}\frac{F_a}{S_a} + \frac{\upsilon}{E}\left[\frac{E_b}{S_b} + \frac{E_c}{S_c}\right] = -\frac{1}{E}P + 2\frac{\upsilon}{E}P = -(1-2\upsilon)\frac{P}{E} \\ \frac{\Delta V}{V} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c} = -3(1-2\upsilon)\frac{P}{E} \Rightarrow 3(1-2\upsilon)\frac{1}{E} = -\frac{1}{P}\frac{\Delta V}{V} \qquad (2)\end{array}\right\}$$

From (1) and (2), then $\chi = 3\frac{(1-2\upsilon)}{E}$, this relationship imposes that υ **<1/2.**

d. Modulus of stiffness:

Force **F** is a tangential force. The normal edges at the plane of application of the force rotate a small angle **α**, see **figure 5.**

$\alpha = \frac{F}{GS}$, knowing that **E**, **G** sometimes also noted μ and υ are connected by the relation:

$E = 2G(1+\upsilon)$, **G** is the shear modulus (Coulomb).

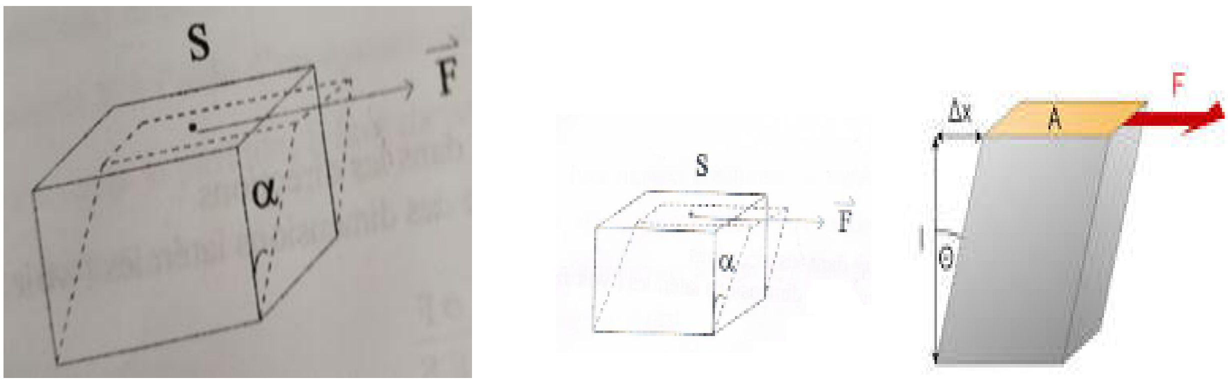


Figure 5 : Shear principle

e. Torsion:

Consider a cylindrical rod in Figure 6. The elementary force df applied to dS is $df = \alpha G ds$. Then the sum of the elementary moments on the circle is $\int d\Gamma = \alpha G \int_{Cercle} rds = \alpha G \int r\,(2\pi r)dr$

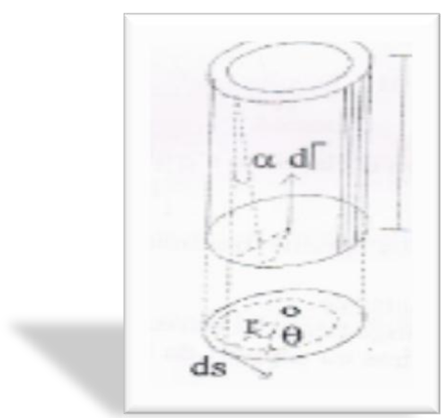


Figure 6: Torsion effect on the rod

For a rod full of radius **R**, we replace **α** by: $\alpha l = r\theta \Rightarrow \alpha = \frac{r\theta}{l}$

The result is:

$$\Gamma = \int_0^R \frac{r\theta}{l} G\, r(2\pi r)dr = \int_0^R \frac{r^3\theta}{l} G\,(2\pi)dr = \frac{\pi}{2} G \frac{R^4}{l}\theta = C\theta$$

The physical magnitude is proportional to θ within the limits of elastic deformations.

II- Dynamic Study:

The bar moves in harmonic vibratory motion around its balance potion, the system undergoes the following equation:

$$\sum(moments\ des\ \text{forces})_{/\Delta} = I\frac{d^2\theta}{dt^2} = -C\theta \Rightarrow \frac{d^2\theta}{dt^2} + \frac{C}{I}\theta = 0 \Leftrightarrow \frac{d^2\theta}{dt^2} + w^2\theta$$

With $w^2 = \frac{C}{I}$ et $T = \frac{2\pi}{w} = 2\pi\sqrt{\frac{I}{C}}$, where **I** is the moment of inertia along the axis of rotation relative to **Δ** .

❖ Stem Parameters

- **Torsion constant:**

  It is calculated by the following formula: $C = \frac{\pi}{2}\frac{R^4}{l}G$

  where **R**: radius of the rod, **l**: length of the rod and **G**: modulus of Coulomb or modulus of transverse elasticity (shear) expressed in **N.m^{-2}**.

- **Coulomb module:**

  It is calculated by: $G = \frac{E}{2(1+\upsilon)}$ with **E** : Young module of the stem and υ : Poisson coefficient.

Table 1 shows experimental data of Young **E** modulus and Poisson coefficient of υ some materials.

Table 1: Young module and Poisson coefficient values

Materials	Young E module in MPa	Fish coefficient υ
Structural steel	210.000	0.27 – 0.30
Stainless steel	203.000	0.30 – 0.31
Fontes	83.000 à 170.000	0.21 – 0.26
Brass (Cu + Zn)	100.000 à 130.000	0.37
Aluminium (Al)	69.000	0.346
Copper (Cu)	124.000	0.33
Titanium (Ti)	114.000	0.34

III. Assembly and operating procedure:

The assembly is carried out according to **figure 7.** It is necessary to check that the rods with vertical torsion on the beam and to avoid extreme oscillations.

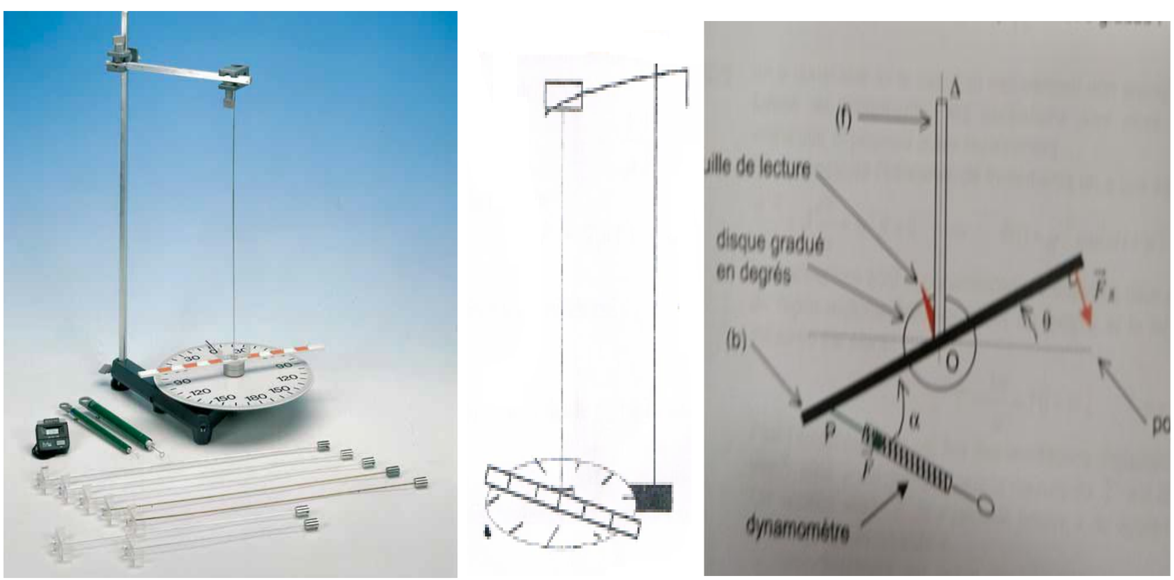


Figure 7: Experimental design.

III- Work required:

- Measure the diameter of the metal rod for different locations and write the result as **$d = (d_0 \pm \Delta d)$ m**. Take measurements on different locations of the rod.
- Do the same work for the length.
- Use the dynamometer to measure the force required to balance the bar for a number of rotation **θ.** Vary the distance between the axis of rotation and your measurement point.
- Summarize the results in a table.
- Graph as a function of **θ**.
- Determine **C** byr the least squares method and give its standard deviation **σ** .
- Measure the period **T** of oscillations and deduce the moment of inertia following the axis of rotation.
- Compare the theoretical value with the measured value of the moment of inertia.
- In conclusion indicate the nature of your stem according to **Table 1.**

TP N° 08 : Verification of The Fundamental Law of Circular Motion “Conservation Of Mechanical Energy”

I) Purpose of Handling:

- Determination of the moment of inertia of a disk.
- Determination of the moment of inertia of a rod.

II) Theoretical basis:

II-1) Definition:

Any material point A of mass m animated by a circular motion of radius r is subject to a non-zero acceleration (since the speed is not constant in module and direction) and thereafter to a force F = mγ not zero and whose direction is located in the plane of the trajectory. The tangential component is written:

$$F_t = m\frac{dv}{dt} = mr\frac{d\omega}{dt} \Leftrightarrow rF_t = mr^2\frac{d\omega}{dt} \qquad (4.1)$$

Let a solid rotating around an axis . Its various points have same angular velocity **ω** and same angular acceleration $\frac{d\omega}{dt}$. Writing for each point of the rotating solid:

$$\sum rF_t = (\sum mr^2)\frac{d\omega}{dt} \qquad (4.2)$$

The positive quantity mr2 is defined as the moment of inertia of the solid relative to the axis .

II-2) Definition:

The moment of inertia of a body in relation to an axis is called a quantity that measures the inertia of that body in rotation around that axis and is the sum of the products of the elementary masses by the squares of their distances to that axis Δ.

Moment of inertia relative to an axis (Δ):

By definition, the moment of inertia I_Δ, relative to an axis Δ, of a material point of mass **m** at a distance **r** of Δ is: $I_\Delta = mr^2$

A system of **N** material points of mass **m_i**, at a distance of **r_i** from theΔ axis, shall have the moment of inertia in relation to Δ: $I_\Delta = \sum_{i=1}^{N} m_i r_i^2$

In the case of a solid body consisting of an infinity of material points, we will move to the following limit: $I_\Delta = \int r^2 dm$

Moment of inertia relative to an Δ axis parallel to the axis (Δ_G) passing through the center of gravity (Huygens Theorem).

The Huygens Theorem

The moment of inertia of a solid, relative to an axis (Δ), is equal to the moment of this body relative to a Δ_G axis, parallel to Δ, passing through the increased center of gravity of the product Md^2 (M being the mass of the solid and the distance between the two axes).

$$I_\Delta = I_G + Md^2$$

For example, for the cylinder, the moment of inertia in relation to one of its generators will be: $I_\Delta = \frac{1}{2}MR^2 + MR^2 = \frac{3}{2}MR^2$

Theory and exploitation:

Moment of force: either F is a force applied to a point M, we note $\vec{M} = \vec{OM} \wedge \vec{F}$ the momentum of $\vec{F}$ relative to the point O located on an Oz axis. The Γ_z couple exerted by the force $\vec{F}$ in relation to the Oz axis is the projection of $\vec{M}$ on the axis: $\Gamma_z = \vec{M} \bullet \vec{K}$

Kinetic moment theorem:

It is a solid rotating around an O point, fixed in a Galilean reference; we note $\vec{M}$ the moment relative to O of the resulting forces exercising on the solid and $\vec{L}$ the kinetic moment of the solid in relation to O. The kinetic moment theorem says: $\vec{M} = \frac{d\vec{L}}{dt}$.

Moment of inertia:

The moment of inertia **I** relative to an axis of a set of N point masses m_i(i=1,2,3…….,N) is defined by the relationship: $I = \sum_{i=1}^{N} m_i r_i^{\,2}$, where r_i is the distance from the mass m_i to the axis.

The moment of inertia relative to an axis Oz of a solid mass density per unit volume ρ(x, y, z) is given by: $I = \int_{solide} \rho(x,y,z)\,(x^2+y^2)\,dx\,dy\,dz$

Kinetic momentum and angular speed:

Let’s consider a solid turning at angular speed w around a fixed Oz axis. Let **L** be the kinetic moment of the solid relative to point O. It is shown that the projection $\vec{L} \bullet \vec{K} = L_z$ of the kinetic moment **L** on the axis of rotation is given by: $L_z = I\,w$, where **I** is the moment of inertia relative to the axis of rotation.

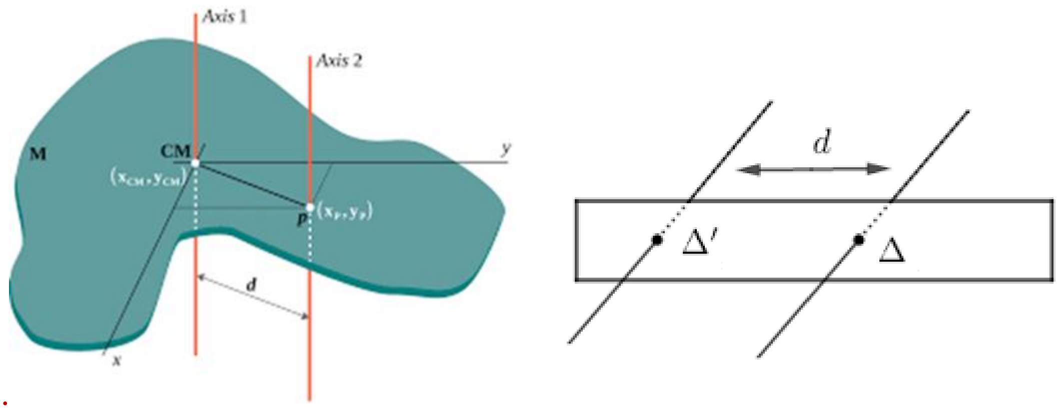


Figure 01: Huygens Theorem

III) Assembly and procedure:

The rotation apparatus consists of:

- **An air bearing** formed from the stator, elbow, shaft and drive pulley. The elbow allows connection to the wind tunnel via the discharge pipe. An air cushion is produced between the stator to eliminate friction. The shaft serves as a guide for centering the rotation disc and the drive pulley for accelerating the rotor. The distance from the pulley to the rotor must not be less than 1cm.

Inertia rod: for the study of correlations between moment of inertia and mass distribution.

Stop device: for the release of the movement of the rotor, the axis under tension of the shutter release jumps back and closes at this time a contact for the start of an electronic stopwatch.

Fork optical barrier: to electronically control the electronic stopwatch. See **figures 02** and **03**.

Determination of angular acceleration, angular velocity and angle as a function of time:

$$\Sigma\vec{F} = m.\vec{a} \quad \Rightarrow \vec{P} + \vec{T} = m.\vec{a}$$

$$\Sigma\vec{M} = I.\vec{\alpha} \quad \Rightarrow \vec{T}\cdot r = I.\vec{\alpha}$$

By projection, we find

$$P - T = m.a \quad \Rightarrow T = P - m.a$$

$$T\cdot r = I\cdot\alpha \Rightarrow (P - m.a)r = I\cdot\alpha$$

We have: $\alpha = \frac{a}{r} \Rightarrow a = \alpha.r$ and $P.r - m.\alpha.r^2 = I.\alpha \Rightarrow \alpha = \frac{P.r}{I.+m.r^2}$

$$\Rightarrow \boxed{\alpha = \frac{r.m.g}{I+m.r^2}}$$

Other by: $\alpha = \frac{d\omega}{dt}$ therefore $\frac{d\omega}{dt} = \frac{r.m.g}{I.+m.r^2}$, By integration:

$$\int_0^t \left(\frac{r.m.g}{I+m.r^2}\right) dt = \int_0^\omega d\omega \Rightarrow \boxed{\omega = \frac{r.m.g}{I.+m.r^2}.t} \Rightarrow \omega = \frac{d\varphi}{dt} \text{ therefore } \int_0^t \left(\frac{r.m.g}{I+m.r^2}\right).t.dt$$

$$= \int_0^\varphi d\varphi \Rightarrow \boxed{\varphi = \frac{r.m.g}{2.(I.+m.r^2)}.t^2}, \text{ Hence: } \varphi = \frac{1}{2}\alpha.t^2$$

IV) Work to be done:

Handling 01: Moment of inertia of the disc

- Measure the time it takes to turn the disc around completely.

- Determine for each case the angular acceleration $\alpha'' = \frac{2\pi}{t^2}$ and the moment M=F.r (r: radius of the rotor).
  - Complete the following table:

Driving weights	m (Kg)				
Driving forces	F(N)				
U-turn time	t (s)				
Angular acceleration	$\alpha'' = \frac{2\pi}{t^2}$				
Timing applied	$M = F.r$				

  - Draw the curve M=f (α"). Conclude.
  - Deduce the moment of inertia Iz of the disc.
  - Give the uncertainty it that is affected by.
  - Compare this value to the theoretically calculated value.
  - Make a conclusion.

Handling n° 02: Moment of inertia of a rod

We measure the duration of a complete half-revolution. We can then determine α" and the moment of the driving force.

- Complete the following table:

Driving weights	m (Kg)				
Driving forces	F(N)				
U-turn time	t (s)				
Angular acceleration	$\alpha'' = \frac{2\pi}{t^2}$				
Timing applied	$M = F.r$				

• Draw the curve M=f(α"). Conclude.

• Deduce the moment of inertia I_z of the stem.

• Give the uncertainty it that is affected by.

• Compare this value to the theoretically calculated value.

• Make a conclusion.

V) **Digital characteristics of the apparatus:**

o Disc mass = (829 ±1) g.

o Disc radius = (17.50± 0.01) cm.

o Stem mass = (158 ±1) cm.

o Rotor radius = (…. ±Δx) cm, t = 0.01s.

o The motor mass tolerance is Δm = 0.01g.

VI) The inertia moment mount of the disc:

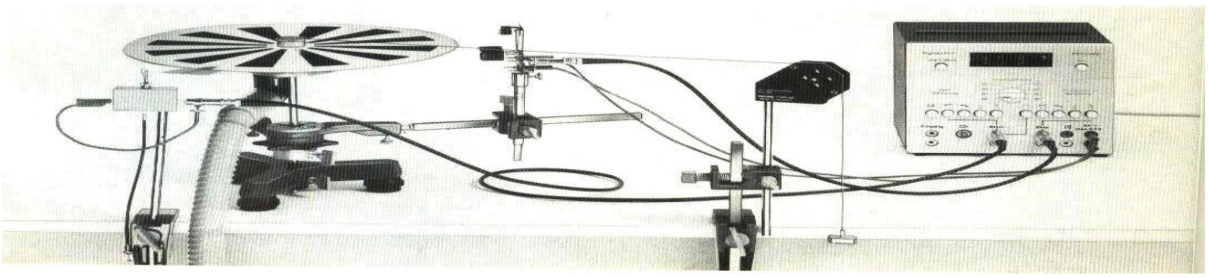


Figure 02: Inertia moment assembly

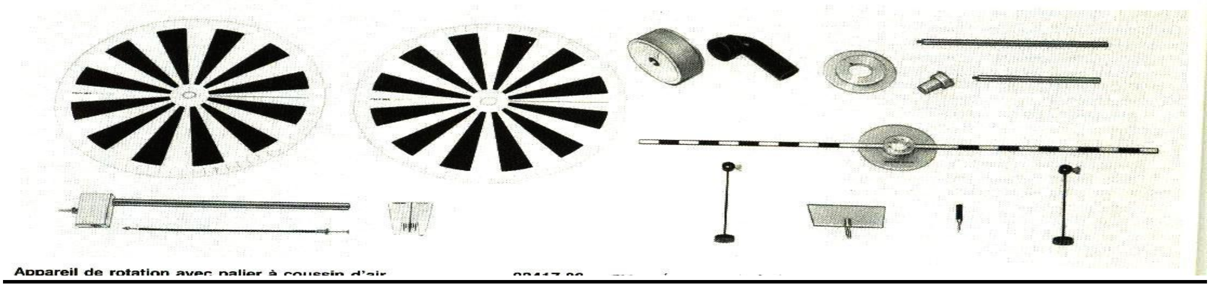


Figure 03: Handling Instruments

TP N° 09 : Collision Laws

I) Purpose of Handling:

The aim of this work is to experimentally illustrate the principles of impulse conservation (momentum) and post-shock mechanical energy for an isolated system.

II) Principle:

On an air cushion bench (in order to eliminate friction) elastic shock and soft shock are measured, the speeds before and after the impact of two trolleys move on the bench, see **figure 1**. To understand the concept of inertia force and centrifugal force in the case of a body rotating around a fixed axis.

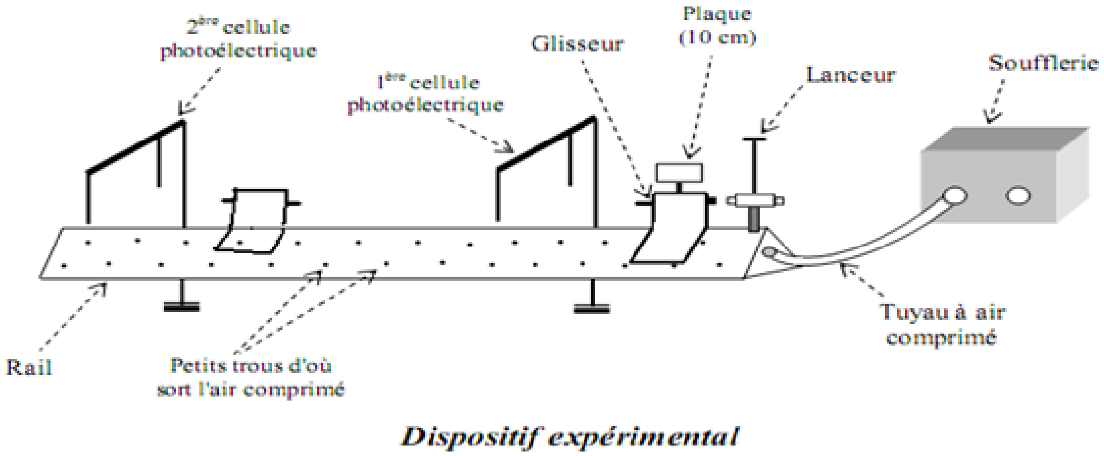
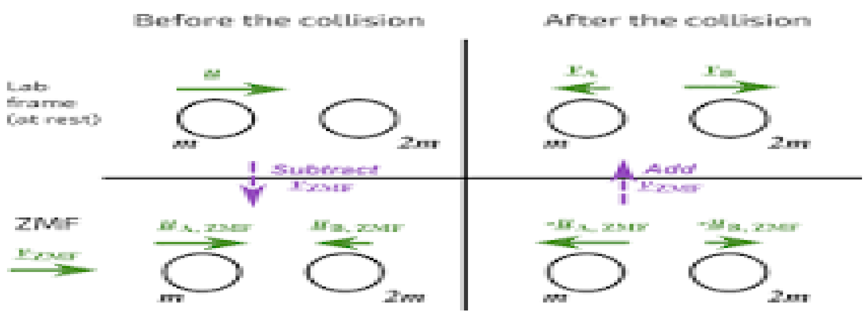


Figure 1: Operating Mode Instruments

There are two types of collisions:

- Inelastic collisions: momentum is conserved,
- Elastic collisions: momentum is conserved and kinetic energy is conserved.



III) Assembly and procedure:

⌖ The launching device is used to start the trolley.

⌖ The calculation of the pulse is determined from the measurement of the speed of the trolley. To perform this measurement, the darkening time caused by the plugged-in screen during its passage through the beam of the following light barrier is used: $V = \frac{\Delta S}{\Delta t}$ (9-1)

Where **ΔS** : screen length, **Δt**: dark time

This time is obtained most simply by measurement once the **STOP-INVERT** button is pressed and the other time not pressed. The time difference: $\mathbf{t_2 - t_1 = \Delta t}$ is the time the screen passes in front of the light beam.

If mass ratios are changed, care must be taken to ensure that the additional masses are modified symmetrically each time. The 4-decade meter is connected according to **figure 2**.

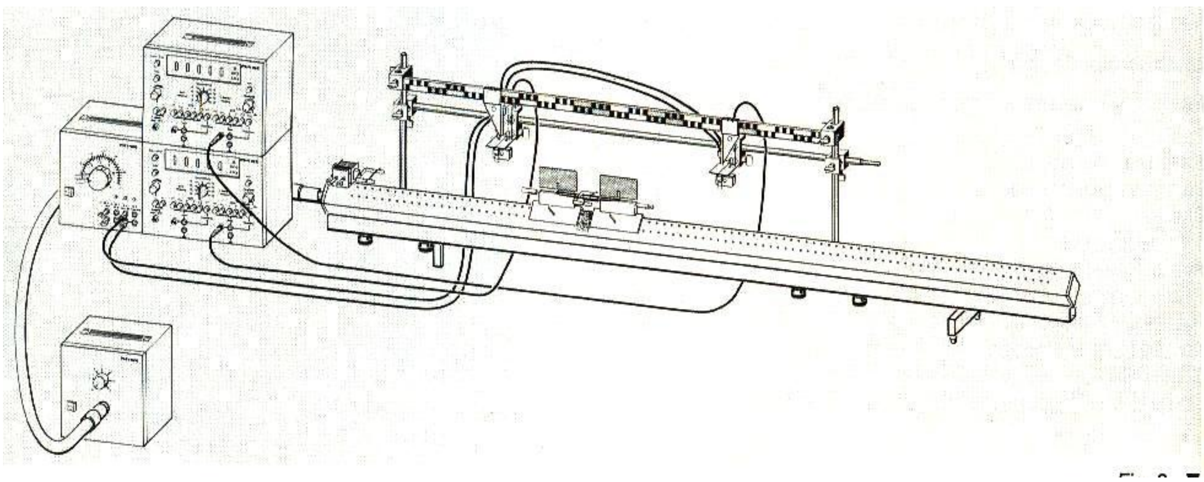


Figure 2: Assembly of collision laws

N.B: Check the bench leveling before measurements.

IV) Theoretical basis

A. Elastic Shock:

During an elastic shock between two bodies (trolleys) of masses m_1 and m_2 the kinetic energy and the pulse are preserved.

$$\frac{\vec{P}_1^{\,2}}{2m_1}+\frac{\vec{P}_2^{\,2}}{2m_2}=\frac{\vec{P}_1^{\,'2}}{2m_1}+\frac{\vec{p}_2^{\,'2}}{2m_2} \qquad (9\text{-}2)$$

$$\vec{P}_1+\vec{P}_2=\vec{P}_1^{\,'}+\vec{P}_2^{\,'} \qquad (9\text{-}3)$$

P_1 and **P_2** are the pulses before the shock. **P'_1** and **P'_2** are the pulses after the shock.

For a central elastic shock, i.e., the trolley (2) is at rest. The following equations are obtained for **$P_2 = 0$**:

$$\frac{\vec{P}_1^{\,2}}{2m_1}=\frac{\vec{P}_1^{\,'2}}{2m_1}+\frac{\vec{p}_2^{\,'2}}{2m_2} \qquad (9\text{-}4)$$

$$\vec{P}_1=\vec{P}_1^{\,'}+\vec{P}_2^{\,'} \qquad (9\text{-}5)$$

Combining (4) and (5) yields:

$$\vec{P}_1^{\,'}=\frac{m_1-m_2}{m_1+m_2}\vec{P}_1=-\frac{1-\frac{m_1}{m_2}}{1+\frac{m_1}{m_2}}\vec{P}_1 \qquad (9\text{-}6)$$

$$\vec{P}_2^{\,'}=\frac{2m_2}{m_1+m_2}\vec{P}_1=\frac{2}{1+\frac{m_1}{m_2}}\vec{P}_1 \qquad (9\text{-}7)$$

B. Soft shock:

For soft shocks only pulses are preserved c – to – d: $\vec{P}_1+\vec{P}_2=\vec{P}_1^{\,'}+\vec{P}_2^{\,'}$ (9-8)

The second trolley is at rest, $P_2 = 0$. Equation (2-8) becomes: $\vec{P}_1=\vec{P}_1^{\,'}+\vec{P}_2^{\,'}$ (9-9)

Similarly, the speeds of the two bodies after impact are identical.

$$\vec{V}_1^{'} = \vec{V}_2^{'} \Rightarrow \frac{\vec{P}'_1}{m_1} = \frac{\vec{P}_2^{'}}{m_2} \qquad (9\text{-}10)$$

Combining (2-9) and (2-10) results in: $\vec{P}_1^{'} = \frac{1}{1+\frac{m_2}{m_1}}\vec{P}_1$ (9-11)

$$\vec{P}_2^{'} = \frac{1}{1+\frac{m_1}{m_2}}\vec{P}_1 \qquad (9\text{-}12)$$

V) Work to be performed:

V-I. Elastic shock:

The launching device starts the trolley (1) whose mass is $\mathbf{m_1=202g}$. This trolley is equipped with a screen of length **l=100 mm**. The speed of the trolley is calculated after equation (9-1), so we know the pulse $\mathbf{P_1}$ before the impact.

Shock pulses are found after (9-6) and (9-7).

- Repeat the same operation for different masses.
- Put the results in the following table:

m_1/m_2				
Δt_1(s)				
V_1 (m/s)				
Δt_2(s)				
V'_2(m/s)				
P_1 (kg m/s)				
P'_2 (kg m/s)				
P'_1 (kg m/s)				

Draw on the same graph: $P_1^{'} = f(m_1/m_2)$, $P_2^{'} = f(m_1/m_2)$ and $P^{'} = f(m_1/m_2)$

Where: $\vec{P}^{'} = \vec{P}_1^{'} + \vec{P}_2^{'}$, $\vec{P}^{'}$: Total pulse after shock

V-II. Soft shock:

We repeat the same work previously except that the second trolley is replaced by a soft body.

Put all results in the following table:

m_1/m_2				
Δt_1(s)				
V_1 (m/s)				
Δt_2(s)				
V'_2(m/s)				
P_1 (kg m/s)				
P'_2 (kg m/s)				
P'_1 (kg m/s)				

- Draw on the same graph:

$P_1^{'} = f(m_1/m_2)$, $P_2^{'} = f(m_1/m_2)$ and $P^{'} = f(m_1/m_2)$

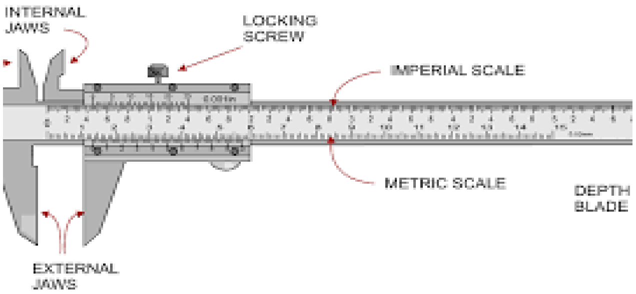
- Interpret and conclude.

Annex

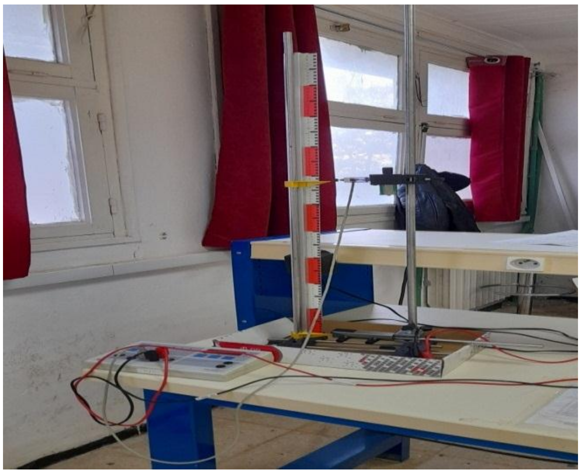
The formulas that govern the motion dynamics of rectilinear translation and rotation.

Motion	Translation	quantities	Rotation	quantities
Newton’s 2nd law	$\sum \vec{F} = m\,\vec{a} = \frac{d\vec{P}}{dt}$ $\vec{a} = \frac{d\vec{V}}{dt} = \frac{d^2 r}{dt^2}$ $\vec{r}$: position vector	$\vec{F}$: force, $\vec{a}$: acceleration, $\vec{P}$: momentum	$\sum \vec{M}_0 = I\ddot{\theta} = \frac{d\vec{L}}{dt}$ $\sum \vec{M}_0 = \vec{r} \wedge \vec{F}$ $\dot{\theta} = \frac{d\theta}{dt}$, $\ddot{\theta} = \frac{d^2\theta}{dt^2}$	$\vec{M}_0$: Moment of force $\ddot{\theta}$: Angular acceleration, $\vec{r}$: arm
momentum	$\vec{P} = m\vec{V}$	$\vec{V}$: linear velocity	$\vec{L} = \vec{r} \wedge \vec{P}$ $\vec{L} = I\dot{\theta}$	$\vec{L}$ kinetic moment
Main size	mass **m**	$\dot{\theta}$: angular velocity	$I = \sum mR^2$ R : disc radius	I : moment of inertia

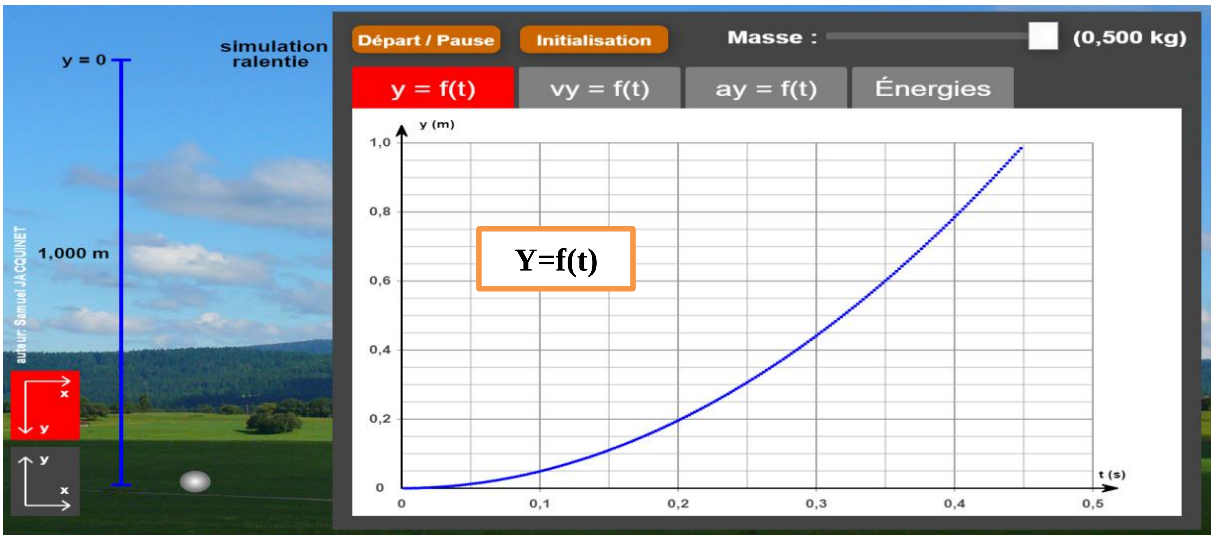
Photo Vernier caliper

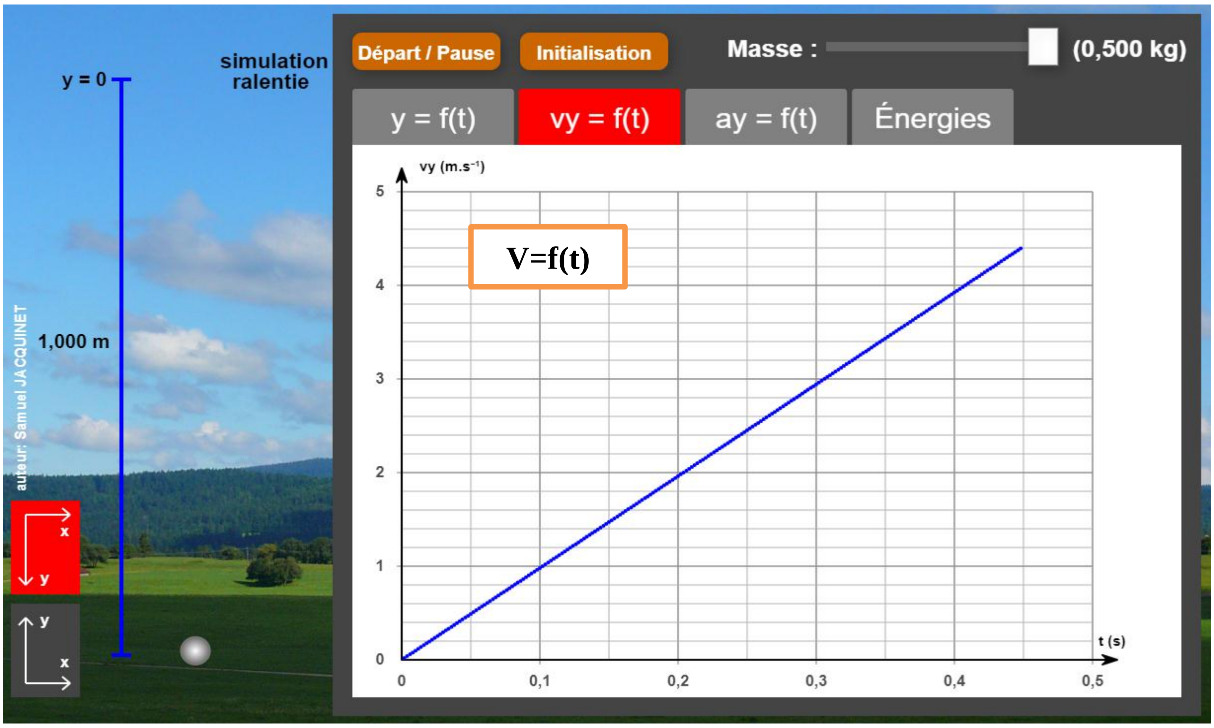


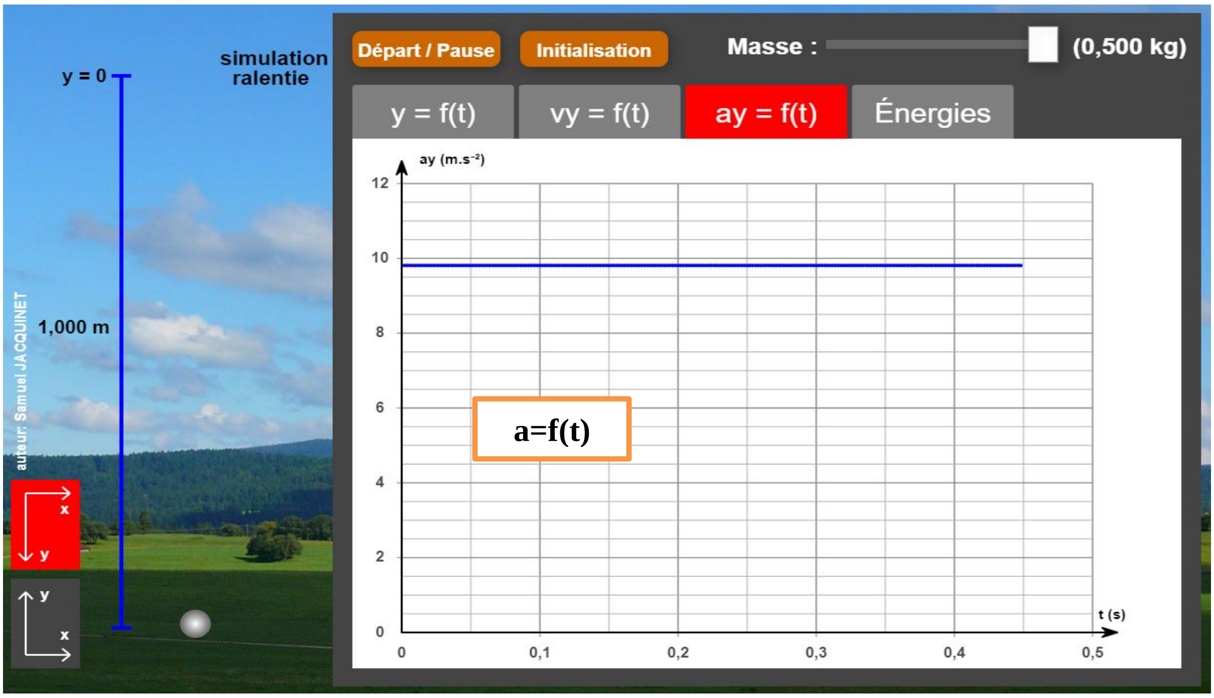
1-Photo Free fall

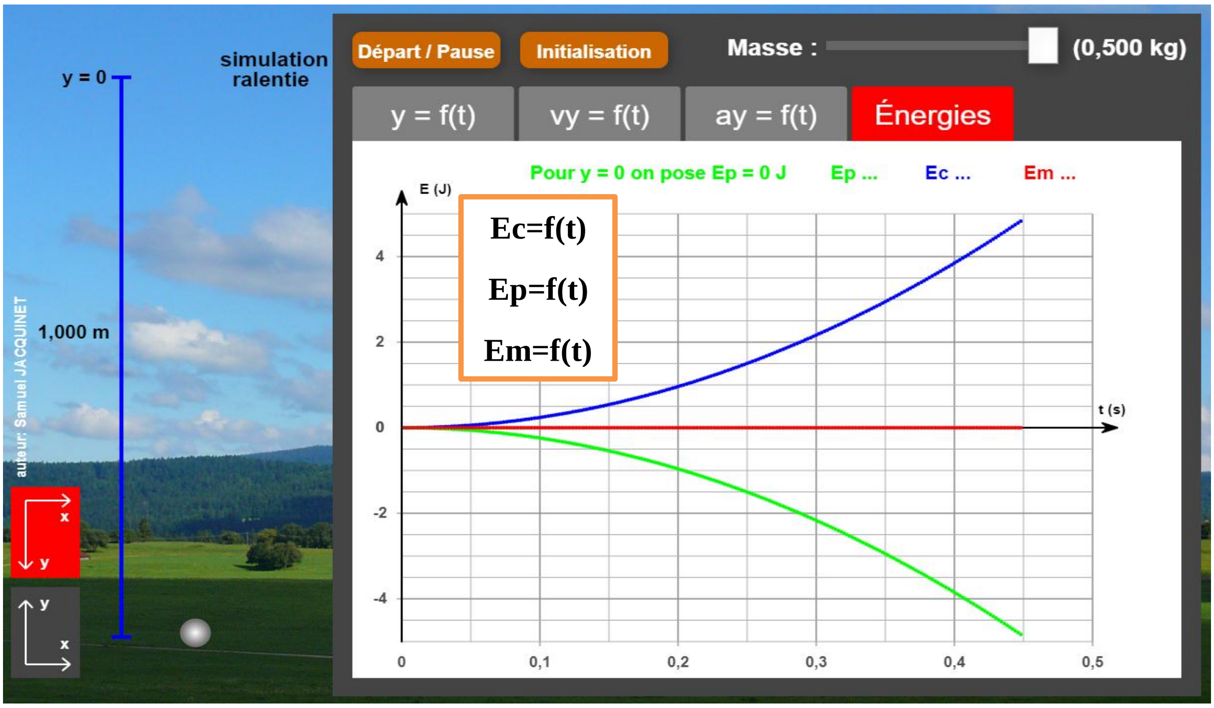


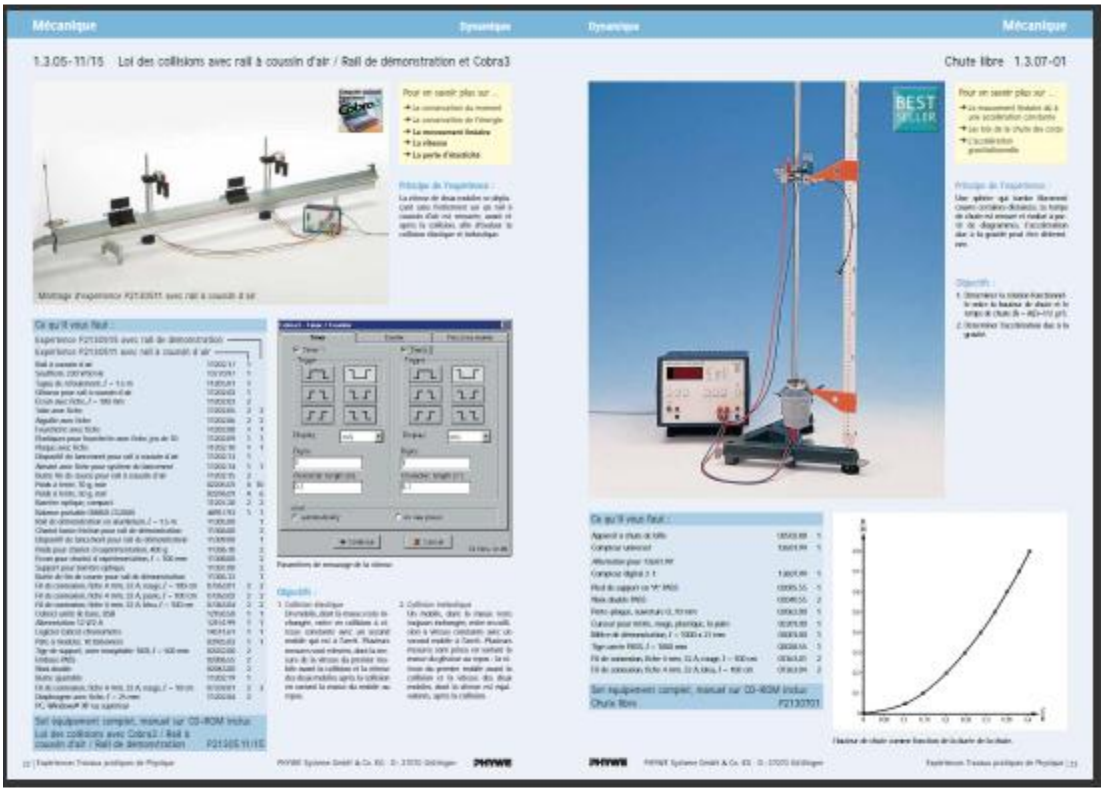
Free Fall Graphics



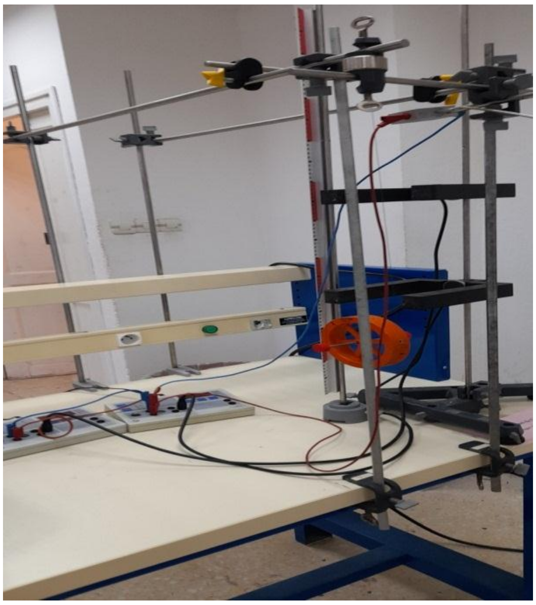



simulation ralentie
y = 0
1,000 m
auteur: Samuel JACQUINET
Départ / Pause
Initialisation
Masse :
(0,500 kg)
y = f(t)
vy = f(t)
ay = f(t)
Énergies
ay (m.s⁻²)
t (s)
a=f(t)


simulation ralentie
y = 0
1,000 m
auteur: Samuel JACQUINET
Départ / Pause
Initialisation
Masse :
(0,500 kg)
y = f(t)
vy = f(t)
ay = f(t)
Énergies
Pour y = 0 on pose Ep = 0 J
Ep ...
Ec ...
Em ...
E (J)
t (s)
Ec=f(t)
Ep=f(t)
Em=f(t)

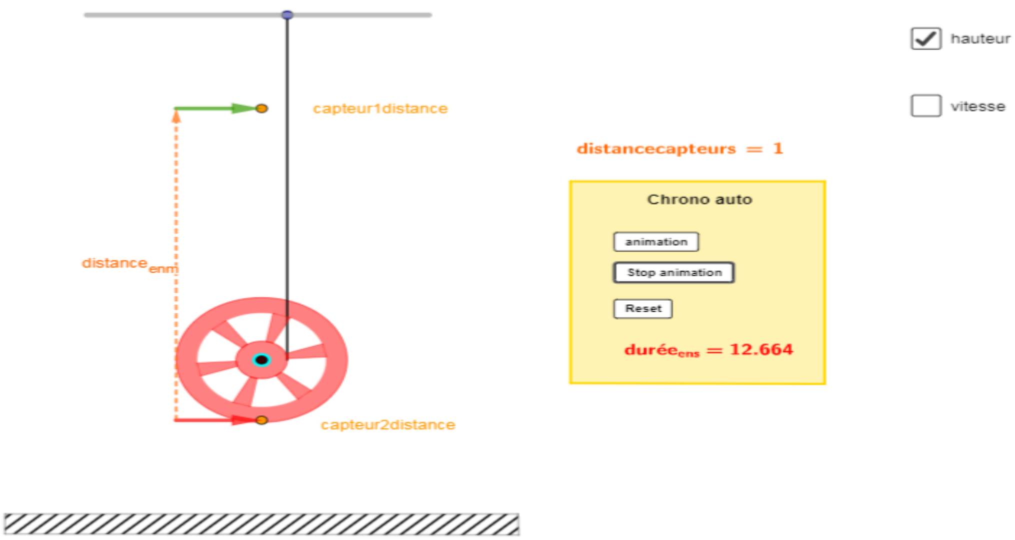


2- Photo Maxwell wheel




Mécanique
Dynamique
Dynamique
Mécanique
1.3.16-11 Force centrifuge avec Cobra3
Conservation mécanique de l'énergie 1.3.18-00
BEST SELLER

Animation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distance_enm
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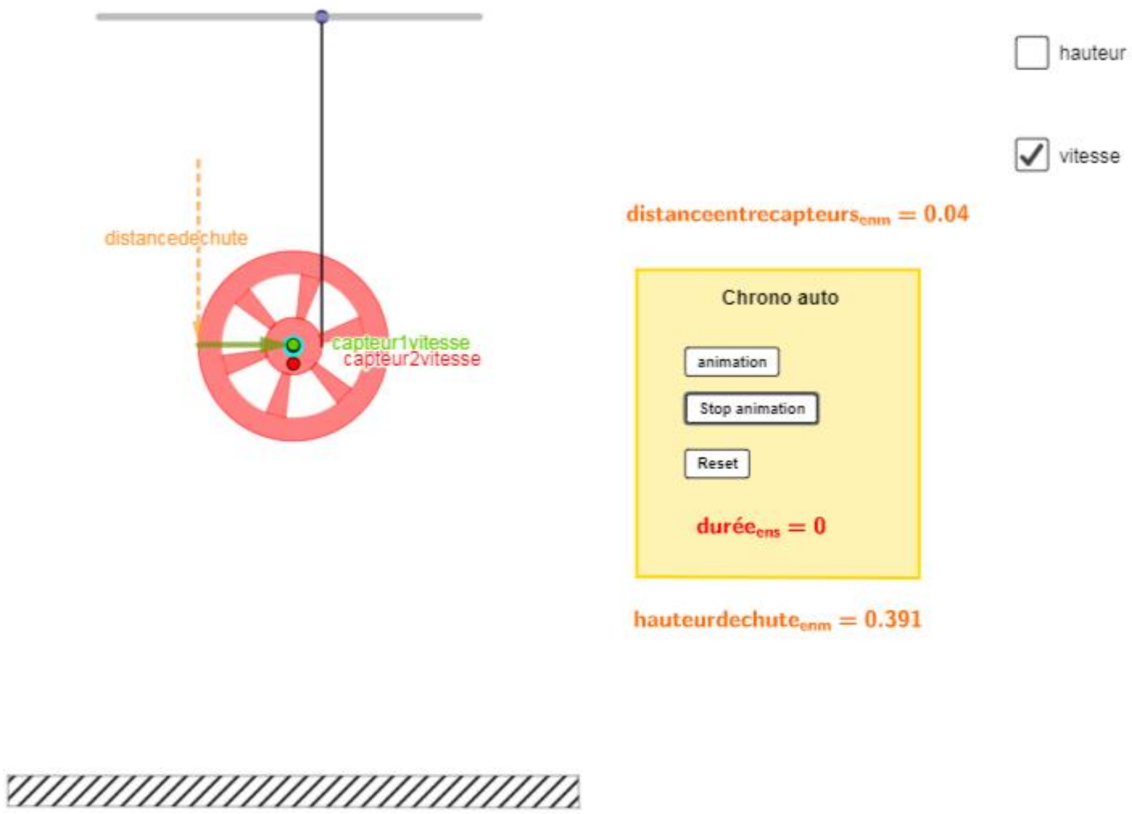
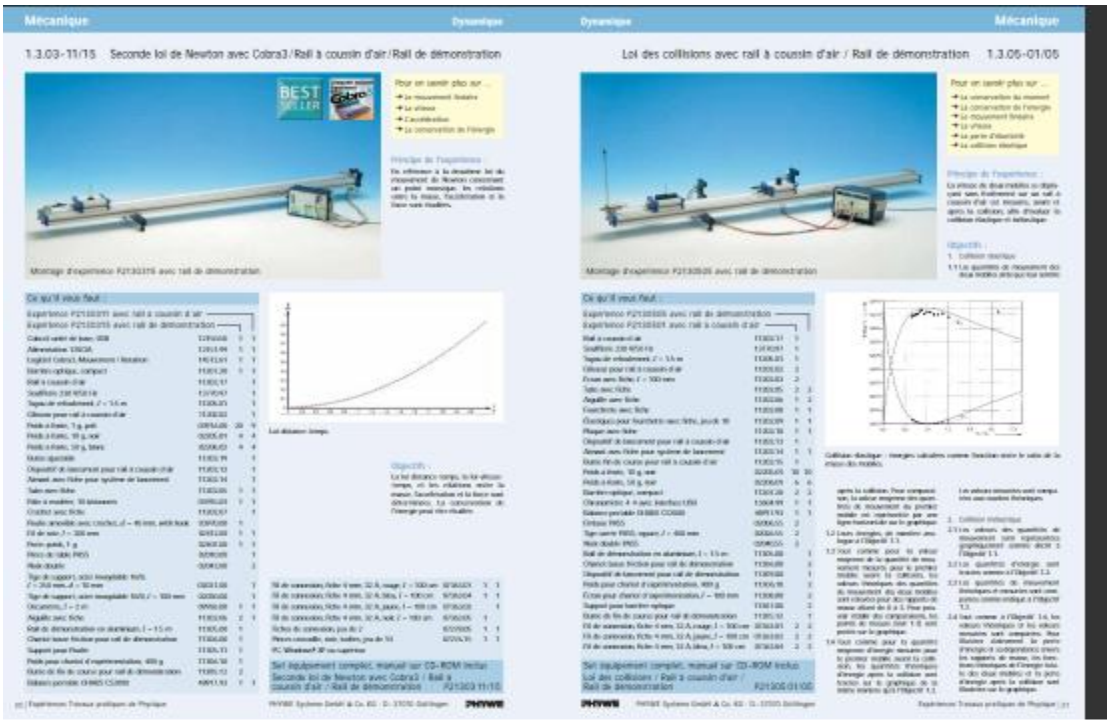
Stop animation
Reset
durée_ens = 12.664



3- Collision laws



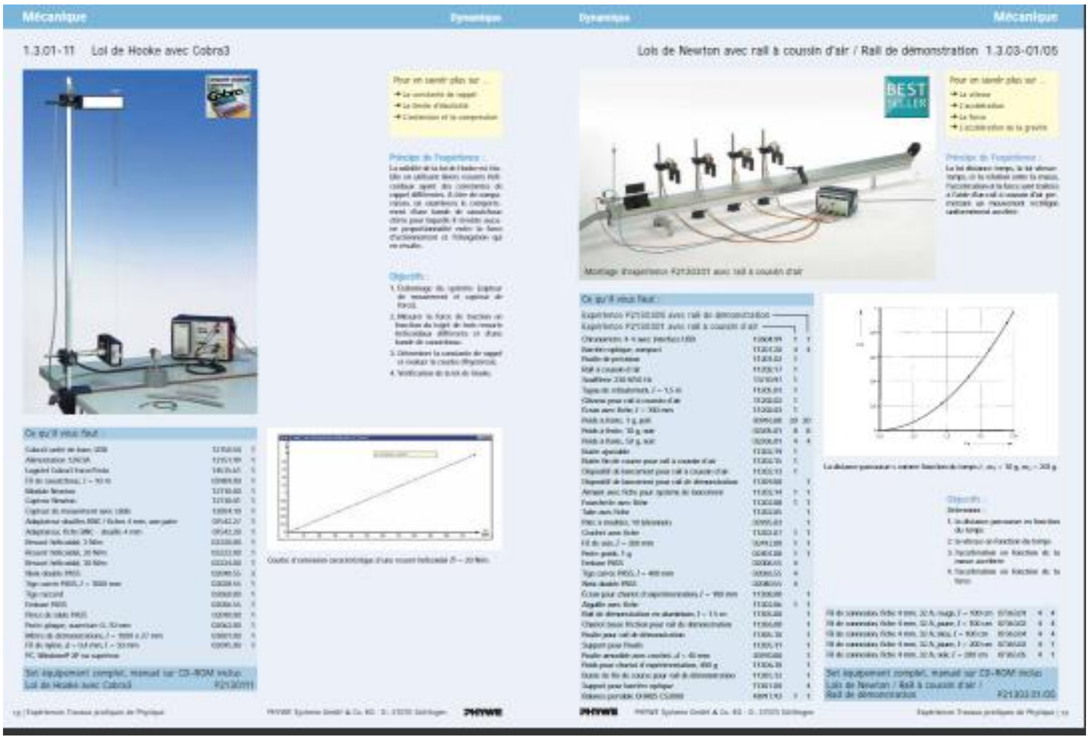
Mécanique — Dynamique

1.3.03-11/15 Seconde loi de Newton avec Cobra3 / Rail à coussin d'air / Rail de démonstration

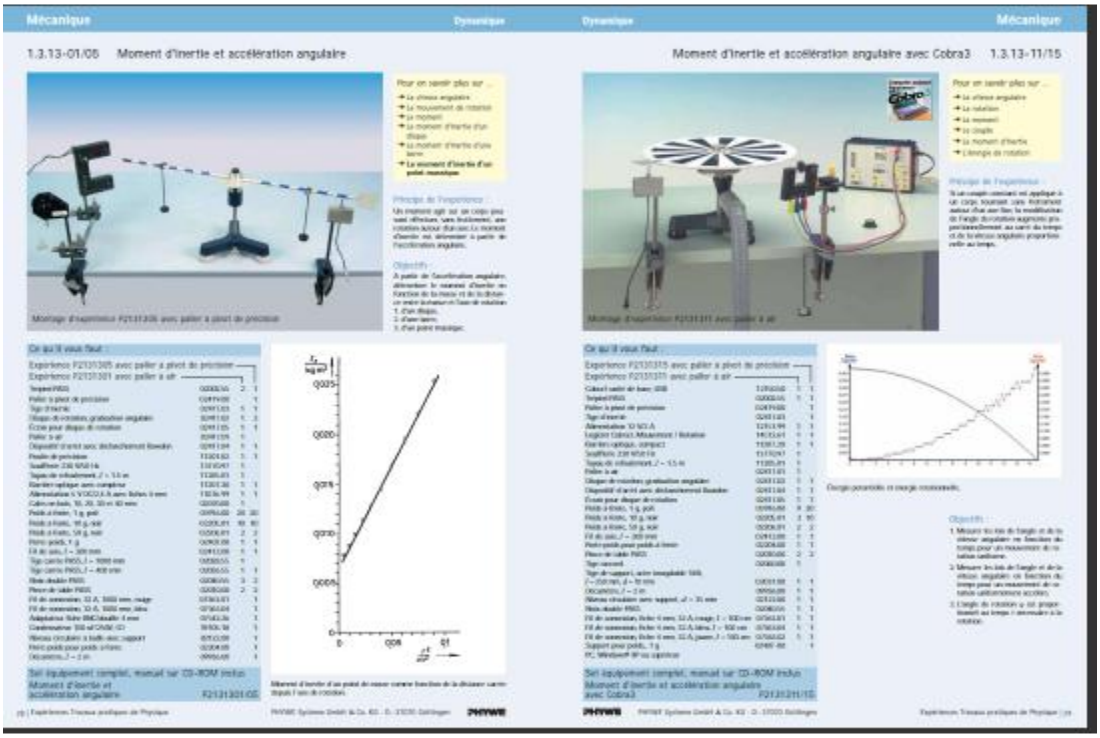
Dynamique — Mécanique

Loi des collisions avec rail à coussin d'air / Rail de démonstration 1.3.05-01/05

4- Laws of Newton

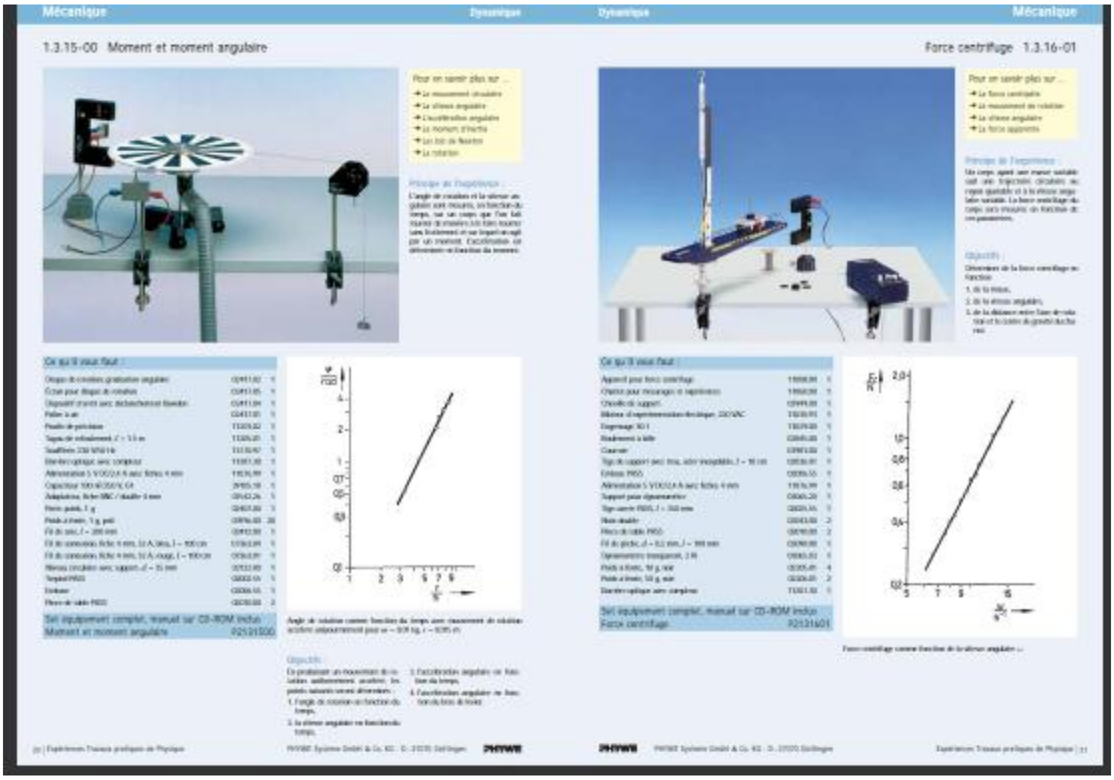


5- Photo Moment of inertian.


Mécanique Dynamique Dynamique Mécanique

1.3.13-01/05 Moment d'inertie et accélération angulaire

Moment d'inertie et accélération angulaire avec Cobra3 1.3.13-11/15



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3- https://www.geogebra.org/m/mxh92jng