# 1-Translational motion: Energy and momentum in elastic and inelastic collisions

**Objectives:**

(a) Check the properties of uniform movement and of uniformly accelerated movement
(b) To calculate the velocities before and after collisions in case of both elastic and inelastic collisions.
(c) To verify law of conservation of momentum and energies.

**Experimental Setup:**

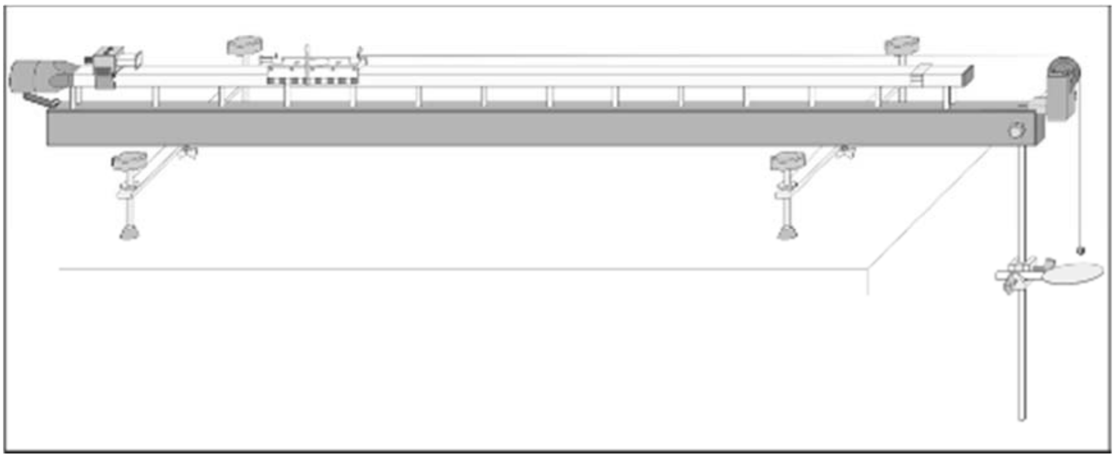


**Figure 1.1** : Experimental setup for air bench movement and collision

**Equipment :**

The equipment consists of an air track on which a slider of variable mass slides without friction, thanks to the air cushion. Put the slider on the track rail, and increase the air supply slowly until the slider slides on the rail without friction. Forked light barriers can be set at any distance using the holding magnet. They can give the time transit of the yellow stem interrupters in front of the light barrier and the time of travelling between the two barriers. The velocity v of the slider can be calculated from v=w/t, where w is the width of the yellow stem acting as beam interrupter on the slider and t the transit time.

In case of collisions, two sliders are mounted on the air track. The first slider is equipped with an impact spring and second one with an impact plate in case of elastic collisions as shown figure 1.2. In case of inelastic collisions, the first slider is equipped with a needle and the second one with a tube filled with plasticine as shown on figure 1.2.

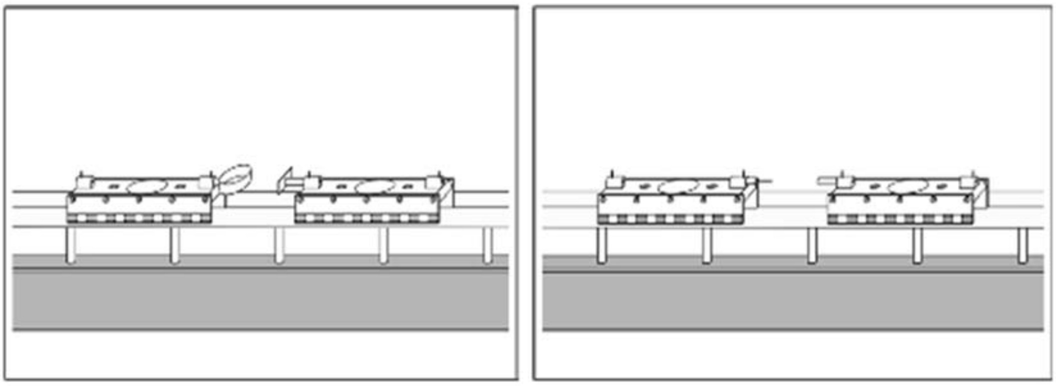


**Figure 1.2** :mobile for (a) Elastic collision and (b) Inelastic collision

**Movement of a single slider, theory:**

Consider a single slider of mass M on a nearly frictionless air track. As the bench is perfectly horizontal, the gravity is exactly compensated by the air cushion small. So, to get some gravity acceleration, a guide pulley is used : the mass m is attached to the slider by a string passing over the pulley, so that a vertical movement of the mass is converted to an horizontal movement of the slider. The gravitational force on the small mass is equal in magnitude to its weight mg.

We can say that the gravitational force causes the entire system of mass M+m to accelerate. Newton's second law can then be written as

$$mg = (M+m)a \tag{1.1}$$

Thus, the acceleration is given by

$$a = \frac{mg}{m+M} \tag{1.2}$$

**Experiment procedure** :

(a) Put the first optical gate somewhere near the start of the track and the second one near the end of the track.
(b) Measure the length w of the small light screen (little yellow stem) mounted on the slider and the distance between the two optical gates.
(c) Make sure the slider is completely free, it must not be connected to the pulley and a mass
(d) Put the stop watch box in the mode "$t_{E,F}$". Put the slider at the start of the track. Make sure the stop watch shows 0.000 and press "Start".
(e) Throw the slider towards the two gates and wait for it to have reached the other end of the track.
(f) Using the second "$t_{E,F}$" button (lower and right part of the front panel), check the the two screening times $t_1$ and $t_2$ of the slider when it has gone through the two gates and

write them down. Pressing again on "$t_{E,F}$", write the transit time $t_{12}$ from optical gate 1 to optical gate 2.

(g) Calculate each of the velocities you can deduce from these three durations. What should you find according to theory? Does is work?

**Uniformly accelerated movement** :

(a) Take a string and tie to the slider. Put the slider against the end of the track to get a reproducible initial position. Unroll the string, put it around the pulley and put a mass at the end of the string. Check the weight of the mass.
(b) Put the first optical gate very near the starting point and the second one somewhere else on the track.
(c) Measure precisely the position the gate, take the yellow stem when the slider is at its starting position as the origin.
(d) Put the stop watch box in the mode "$t_{E,F}$". Make sure the stop watch shows 0.000 and press "Start". Release the slider and check the times $t_1$, $t_2$ and $t_{12}$.
(e) Without moving the optical Repeat the experiment to check if it is reproducible .
(f) Without moving the first optical gate, move the second one to check velocity at another point on the track and repeat the experiment.
(g) Repeat the experiment for different position of gate 2, until you have data everywhere along the track.
(h) From theory, what is predicted for v(t), x(t) and v(x)?
(i) Using some plot you should defined, check if this prediction is true.
(j) Repeat this experiment for a trolley with some ballast to change its mass.

**Analysis** : plot the data the right way to show that this movement is indeed uniformly accelerated. Check if the acceleration corresponds to what you could expect from the pulling mass.

**Elastic collisions between two sliders**

An elastic collision is one in which the internal forces are conservative, so that both mechanical and internal energy separately stay constant through out collision. In this case, equation for conservation of momentum is written as

$$m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2' \tag{1.3}$$

where $m_i$ is the mass of slider i, $v_i$ its velocity before collision and $v_i'$ its velocity after collision. Note that $v_i$ and $v_i'$ are algebraic quantities, which means that, depending on the direction of the movement, they can be positive or negative. Since kinetic energy is also conserved :

$$\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 = \frac{1}{2}m_1v_1'^2 + \frac{1}{2}m_2v_2'^2 \tag{1.4}$$

Solving above equations together yields the velocities after collision.

$$
\begin{cases}
v_1' = \dfrac{m_1 - m_2}{m_1 + m_2} v_1 + \dfrac{2m_2}{m_1 + m_2} v_2 \\
v_2' = \dfrac{2m_1}{m_1 + m_2} v_1 + \dfrac{m_2 - m_1}{m_1 + m_2} v_2
\end{cases}
\qquad (1.5)
$$

**Experimental Procedure:**

(a) Two sliders of masses $m_1$ and $m_2$ are placed on the air bench. Place the light barriers around distance L/4 and 3L/4 (L being the length of the air bench).
(b) Choose some mass for the sliders and check the weight of the two sliders. Put one of the slider in the middle on the bench, it shouldn't move. Put the other one at one end of the bench.
(c) Prepare the electronic stop watch to record the times (mode "$t_{E,F}$", press button "Start") and throw the slider at the end of the bench to the other one.
(d) Calculate the velocities of the two sliders before and after the collision.
(e) Calculate the all up momentum before and after the collision. Check if equation 3.3 is in agreement with this experiment.
(f) Calculate the all up kinetic energy before and after the collision. Check if equation 3.4 is in agreement with this experiment.
(g) Repeat the experiment with different ratio $m_1/m_2$. Among the cases you should try, there should be $m_1 = m_2$, $m_1 > m_2$ and $m_1 < m_2$.

**Inelastic Collisions:**

In the case of inelastic collisions, the objects can collide and stick together. In inelastic collision, the kinetic energy is not conserved. Instead, some of the initial energy goes into other forms, such as heating the objects or elastic potential energy. In the case the two sliders get sticked, the conservation of momentum is written as:

$$
m_1 v_1 + m_2 v_2 = (m_1 + m_2) v' \qquad (3.6)
$$

where v’ is the final velocity of the two masses.

In this experiment, we record the values of initial and final velocities and check the conservation momentum law.

(a) Put on the sliders the right ending to get the two sliders stuck after collision.
(b) Two sliders of masses $m_1$ and $m_2$ are placed on the air bench. Keep the light barriers around distance L/4 and 3L/4 (L being the length of the air bench).
(c) Choose some mass for the sliders and check the weight of the two sliders. Put one of the slider in the middle on the bench, it shouldn't move. Put the other one at one end of the bench.
(d) Prepare the electronic stop watch to record the times (mode "$t_{E,F}$", press button "Start") and throw the slider at the end of the bench to the other one.
(e) Throw the slider at the end of the bench to the other one.

(f) Calculate the all up momentum before and after collision. Check if the conservation law is right.
(g) Look at what happens to the kinetic energy. Has the all up kinetic energy increase or decrease after collision? How can it be explained?
(h) Repeat the experiment for several values of the ratio $m_1/m_2$. Among the cases you should try, there should be $m_1 = m_2$, $m_1 > m_2$ and $m_1 < m_2$.

# 2-Determination of time period and acceleration of gravity of a simple pendulum

**Objectives**:

(a) To measure the time period of a pendulum
(b) Dependence of the time period of the pendulum oscillations as a function of the distance between the centre of mass and the rotation axis.
(c) To determine the acceleration of gravity from the time period of oscillations.
(d) Dependence of the time period as a function of the oscillations amplitude

**Experimental Setup:**

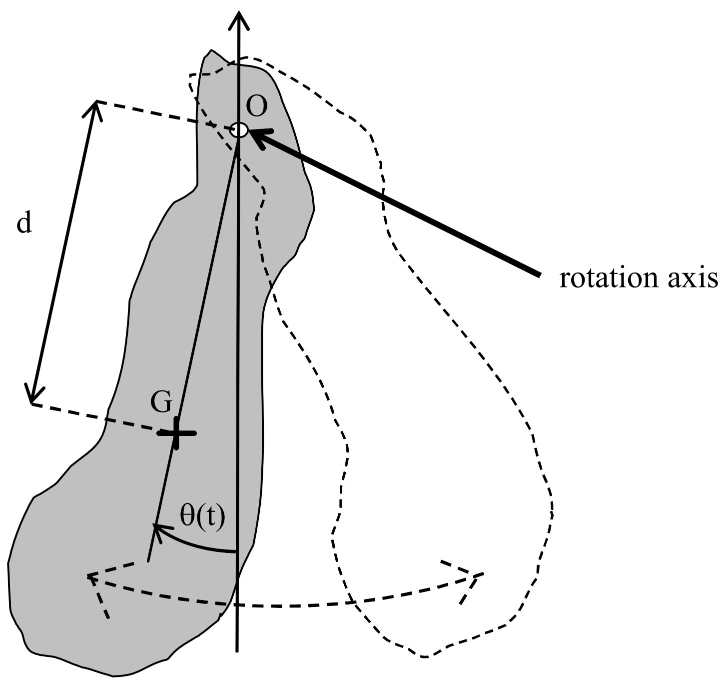



**Figure 2.1** : Experimental setup for pendulum, G being the mass centre

**Theory:**

In case of a solid pendulum, the restoring torque, $\tau$ reduces the angle when the pendulum is displaced from its equilibrium,

$$\tau = mgd\sin\theta \qquad (2.1)$$

where m is the overall mass of the pendulum, g the gravity acceleration, d is the distance from the pivot to the centre of mass and θ the angle the vertical axis and the pendulum axis (see figure 2.1). For small angles $\sin\theta \cong \theta$ (unit for θ must be rad), and Eq. 1 becomes:

$$\tau = mgd\theta \qquad (2.2)$$

Writing the differential form of the torque and setting it equal to Eq. 2, we obtain the equation of motion:

$$\frac{d^2\theta}{dt^2} = -\left(\frac{mgd}{I}\right)\theta \qquad (2.3)$$

where I is the moment of inertia. The solution is given by

$$\theta = \theta_0 \sin(\omega t+\varphi) \qquad (2.4)$$

With :

$$\omega = \sqrt{\frac{mgd}{I}} \qquad (2.5)$$

so that the time for one period is

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{I}{mgd}} \qquad (2.6)$$

For any system, assuming a rotation around the (Ox) horizontal axis, the inertia momentum can be written the following way :

$$I = I_0 + md^2 \qquad (2.7)$$

Where $I_0$ is the inertia momentum we would get when the mass centre G is the same as the origin O. If not, the formula becomes :

$$T = 2\pi\sqrt{\frac{I_0+md^2}{mgd}} \qquad (2.8)$$

**Setup :**

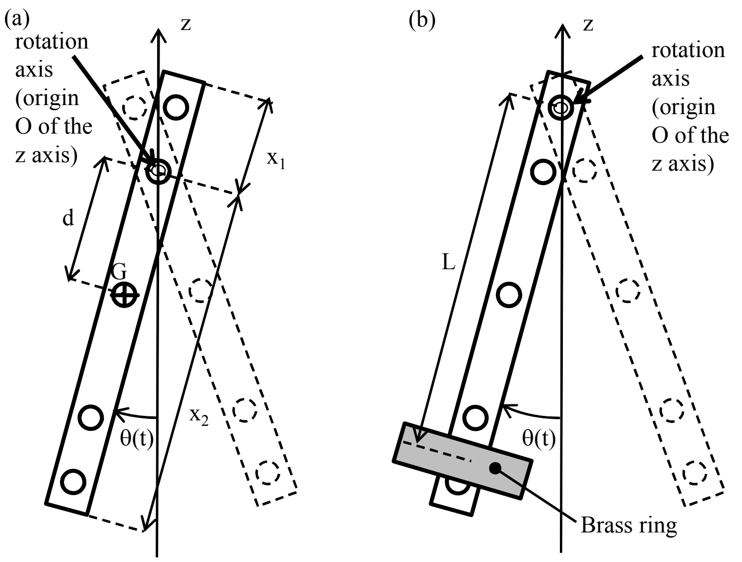



**Figure 2.2 :** configuration of the pendulum according to the set of experiment performed.

**First set of measurements :**

(a) Check the weight m, the length $x_1+x_2$ of the plastic rod and the position of the possible rotation axis.

(b) Putting the plastic rod alone on the axis, check the period of the free oscillations as a function of the position of the axis (the 5 axis are symmetrical, only 3 positions have to be checked). What's happening when the rotation centre is at the middle position of the rod?

(c) Assuming the centre of mass to be in the middle of the rod, plot $T^2 d/(2\pi)^2$ as a function of $d^2$ to get the inertia momentum $I_G$ of the rod.

(d) According to theory, for a rigid wire of negligible section as compared to the length (see figure 2.2.a), inertia momentum should be equal to :

$$I_G = \iiint \rho GM^2 d^3M = \frac{m}{3(x_1+x_2)} x_1^3 + \frac{m}{3(x_1+x_2)} x_2^3$$

Compare your experimental result to this theory.

**Second set of measurements :**

(a) Chose one the two holes at the end of the rod as rotation axis (figure 2.2.b).

(b) Check the weight of the brass ring and put on the plastic rod.

(c) Check the distance between the rotation axis and the average position of the ring.

(d) Measure the period of the oscillations.

(e) Repeat (c) and (d) to get the period T as a function of the position for the widest range of positions possible.

**Analysis :**

When adding the brass ring, formula (2.8) is not true anymore. Starting from formula (2.6), one gets :

$$T = 2\pi\sqrt{\frac{I_0+m_R d^2+m_B L^2}{g(m_R d+m_B L)}} \qquad (2.9)$$

where $m_R$ is the mass of the plastic rod and $m_B$ the mass of the brass ring. Plot $(m_R d+m_B L)T^2$ as a function of $L^2$. What should you get? What can you deduce from the value of the slope?

**Third set of experiment : dependence of time period on the amplitude of the oscillation:**

If the amplitude of the oscillations is too large, the approximation $\sin\theta \cong \theta$ doesn't give anymore the right value. Some corrections which must be added :

$$T = T_0\left(1 + \frac{1}{16}\theta_0^2 + \frac{11}{3072}\theta_0^4 + ...\right) \qquad (2.10)$$

where $T_0$ is the period for oscillations of very small amplitude and $\theta_0$ is the amplitude of the oscillations (unit : radian), that is to say the maximum value of the angle θ.

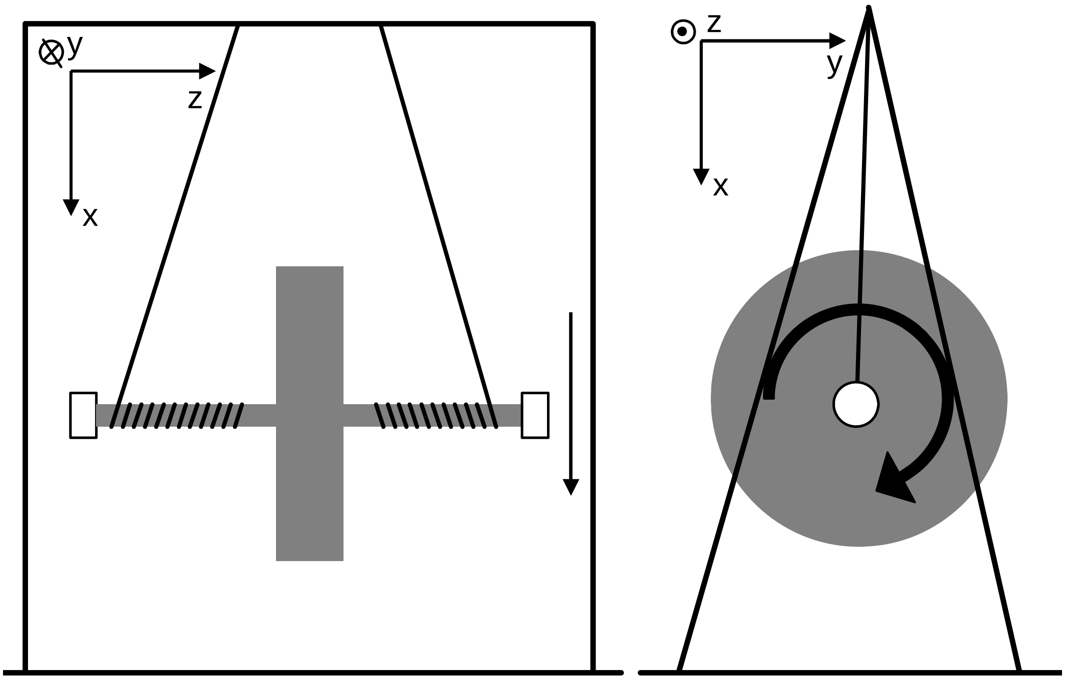
**Experimental Procedure:**

(a) Keep the hole at the end of the rod as the rotation axis. It shouldn't be changed for the next measurements. Put the brass ring as near as possible of the opposite end.
(b) Deflect the pendulum of angle between 0° to 90° and release it to start the oscillations.
(c) Start the CASSY system if it has not been used up to now, because it is the only way to get a measurement precise enough for this part of the experiment.
(d) Record the period T as a function of the amplitude $\theta_0$ of the movement.
(e) Compare your experimental results with the theory. What graph could be plotted to show the effect of amplitude on the period?

# 3-Maxwell's wheel : angular momentum

**1 Aim:** check the properties of a supposedly free fall and see how angular momentum can modify it.

**2 Apparatus :** steel wheel attached to an upper rod with a string rolled around its axis, electronic stop watch, starting switch, optical barrier.




**3 Theoritical results:**
When the wheel is released, it falls down. But, because of the wire tight to its axis, falling down means it has to turn around its axis. It adds a contribution to the kinetic energy, which can be written the following way :

$$K_E = \frac{1}{2} m v_G^2 + \frac{1}{2} I\omega^2 \tag{3.1}$$

where m is the mass of the wheel, G is its mass centre, $v_G = dx_G/dt$ is its velocity and I is the moment of inertia according to its axis. Note that $v_G$ and $\omega$ are not constant, they are time dependent. $\rho$ being the density of the wheel material, the quantity I is defined by :

$$I = \iiint_V \rho r^2 dV \tag{3.2}$$

As the wire (here, it is a chain) is wrapped around the axis, $v_G$ and $\omega$ are not independent, they can be deduced from each other through the following formula :

$$r_{axis}\omega = v_G \tag{3.3}$$

So, kinetic energy can be simplified :

$$K_E = \frac{1}{2}(m + \alpha I)v_G^2 \tag{3.4}$$

with $$\alpha = \frac{1}{r_{axis}^2} \tag{3.5}$$

Potential energy :

$$P_E = -mgx_G \tag{3.6}$$

note that the vertical axis has been chosen as the x axis. Here all forces are coming from potential energy and the total energy is constant :

$$K_E + P_E = \text{constant} \tag{3.7}$$

By derivating this formula, you can deduce the differential equation of the movement :

$$\left(\frac{d^2x_G}{dt^2}\right) = \frac{m}{m+\alpha I}\, g = a_0 \tag{3.8}$$

It is an uniformly accelerated movement, with a reduced acceleration as compared to the free fall of a ball in earth gravity. From this equation, using the starting point of the wheel as the origin of the x axis, the movement is given by :

$$x_G = \frac{1}{2}\, a_0t^2 \tag{3.9}$$

$$v_G = a_0t \tag{3.10}$$

$$\Rightarrow \quad v_G = \sqrt{2a_0x_G} \tag{3.11}$$

**Experimental procedure**

(a) Check the properties of the Maxwell's wheel (weight, average radius of the wheel, radius of the axis around which the string is wrapped, thickness of the string)

(b) Check carefully the height of the wheel axis when the wheel is in contact with the upper switch and write down : this is the origin required to apply formulas (3.9 to 3.11).

(c) Put the digital controller in the mode "$t_{E\rightarrow F}$", mechanical start switch must connected to entry E (grey cable), and optical gate must connected to entry F (black cable)

(d) Choose a first height for the optical gate, check carefully this height.

(e) Wrap carefully the wire around the axis until the wheel almost reaches the mechanical switch on the upper rod.

(f) Without releasing the wheel, press "Start" on the controller.

(g) Wrap a little bit more the string so that the wheel touches the switch and release it immediately. The timer should start and the wheel should also start his fall with almost zero velocity.

(h) The timer stops when the wheel reaches it, you get the duration of the fall. Write down carefully in a table with the height associated.

(i) Repeat this first experiment several times to check if this falling duration is reproducible.

(j) Change the position of the optical gate, write down carefully the new height, and repeat the experiment.

(k) Do this experiment for at least 10 heights of the optical gate, the heights should be distributed as best as possible and should scan the maximum range possible.

**Analysis :**

(a) Plot your data the best way possible to check if it works as predicted.
(b) What can you deduce from the slope of the experiment straight line you have plotted?
(c) Does it fit with the characteristics of the wheel?

**Second set of experiment (for fast students) :**

(a) Put the digital controller in the mode "$t_E$", mechanical start switch must disconnected (grey cable), and optical gate must connected to entry E (black cable)
(b) Choose a first height for the optical gate, check carefully this height.
(c) Wrap carefully the wire around the axis until the wheel almost reaches the mechanical switch on the upper rod.
(d) Without releasing the wheel, press "Start" on the controller.
(e) Wrap a little bit more the string so that the wheel touches the switch and release it immediately.
(f) The timer starts when the lower part of the wheel axis reaches the level of gate beam and stops when the lower part reaches it, releasing the beam. You get the time during which the light beam was stopped by the wheel axis. Write down carefully this time in a table with the height associated.
(g) Repeat this first experiment several times to check if the shadowing duration is reproducible.
(h) Change the position of the optical gate, write down carefully the new height, and repeat the experiment.
(i) Do this experiment for at least 10 heights of the optical gate, the heights should be distributed as best as possible and should scan the maximum range possible.

**Analysis :**

(a) Deduce the velocity as a function of position from your data (third column in your table).
(b) Plot your data the best way possible to check if it works as predicted.
(c) What can you deduce from the slope of the experiment straight line you have plotted?
(d) Does it fit with the characteristics of the wheel and with the previous results?

# 4- Vibrating string experiment

This lab manual describes the objectives of the vibrating string experiments, apparatus to conduct the experiments, experimental procedure and guidelines to carry out the experiment.

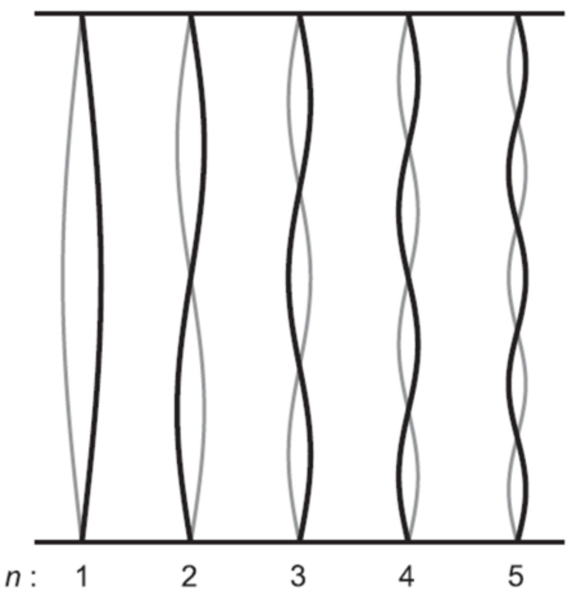
**Objectives**

The objectives of this experiment is to

(a) Investigate transversal waves on an elastic string fastened at both ends.
(b) Generating standing waves as a function of the excitation frequency *f*.
(c) Determining the phase velocity c of the wave.

**Principle**

A wave is formed when two systems capable of coupled oscillation sequentially execute oscillations of the same type. One example of this is the propagation of a transversal wave along an elastic string.




Propagation of waves along a vibrating string is described by the following equation :

$$\frac{\partial^2 y}{\partial t^2} = \frac{T}{\rho}\frac{\partial^2 y}{\partial x^2} \qquad (4.1)$$

Where T is the tension of the string and ρ its lineic mass. The resulting velocity of propagation c is :

$$c = \sqrt{\frac{T}{\rho}} \qquad (4.2)$$

The propagation velocity of an oscillation state is related to the oscillation frequency ***f*** and the wavelength **λ** through the formula

$$c = \lambda f \qquad (4.3)$$

When the string is fixed at both ends, reflections occur at the ends. Standing waves form at certain frequencies as stationary oscillation patterns. The distance between two oscillation nodes or two antinodes of a standing wave corresponds to one half the wavelength. As the ends are fixed, they cannot move, which means that they are antinodes. For a standing wave with n oscillation antinodes on a string with the length L, we can say :

$$L = \frac{n\lambda_n}{2} \qquad n = 1,2,3,.. \tag{4.4}$$

As the phase velocity c does not change, (5.2) implies the excitation frequencies:

$$f_n = \frac{nc}{2L} \tag{4.5}$$

In this experiment, a vertically mounted rubber string is caused to oscillate by means of an electric motor with an oscillation lever at one end of the string. The excitation frequency is continuously adjustable using a function generator.

**Apparatus provided :** small electric motor, rubber string, function generator, stand base, clamping rod, oscilloscope, ruler.

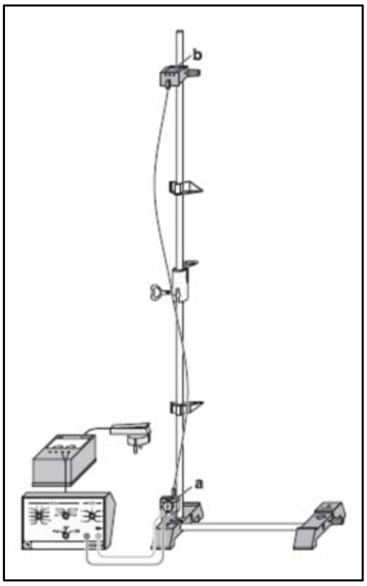



**Figure 5.1 :** sketch of the setup

**Experimental procedure**

(a) Take a rubber string about 60 cm long (unstretched) and check its weight.
(b) Tie its first end to the oscillation lever of the motor and its second end to the support clip.
(c) Attach the motor to a weight of around 200 g. Put it on a balance.
(d) Attach the upper part holding the elastic on the rod, so that the elastic remains unstretched, but is at the limit of being stretched. Measure the length of the elastic.
(e) Move slightly upward the upper end of the elastic, which becomes stretched. Measure the weight on the balance and the length of the elastic.
(f) Repeat these measurements for around 10 values of the elastic length.
(g) How can the tension of the elastic be deduced from this measurement? Plot the tension as a function of the length of your elastic.

**Steady state vibrations of the elastic :**

Note: Depending on the excitation frequency ***f*****,** oscillation states are generated in which the string end attached to the oscillation lever oscillates at a greater amplitude. However, you need to find the frequencies which excite stationary oscillation states at which the oscillation lever moves the least and can be regarded as a fixed end.

(a) Put the motor on the electrical contact, at the bottom of the stand base

(b) Choose some average length for your elastic, measure it precisely and check on your plot what should be its tension. According to your previous measurements, what is its lineic mass?

(c) Switch on the signal generator and look for the frequencies giving an exact integer number of maximum, which means that both ends should not move. Using the oscilloscope, measure the frequencies $f_n$ for which there are n maximum (try to find $f_1$ to at least $f_6$). For your search, start in the range 10-100 Hz.

(d) Repeat the experiment for several values of the length; ranging from almost no tension to a maximum tension of 1 N.

**Results & Calculations**

(a) Tabulate the results for $f_n$ and n

(b) Plot resonant frequency against the number of nodes ($f_n$ vs. n)

(c) Find out the slope of this plot

(d) From the sloped of the plot, determine the wave velocity

(e) Compare the velocities obtained to theory predictions.

**Question** : how can the notes can be tuned on a guitar?

# 5-Velocity of sound using Kundt's tube

**1 Aim:** To measure the velocity of sound in air at room temperature and calculate $\gamma$ for air

**2 Apparatus :** Plexiglas tube containing loud speaker and microphone with power supply, signal generator, oscilloscope.

**3 Theoritical results:** For a standing wave pattern set in air column inside the hollow tube, successive maxima are separated by $\lambda/2$, where $\lambda$ is the wavelength. If the position of successive maxima are given by $y_n$ (n=1,2,3,...), then a plot of $y_n$ versus n gives a straight line with slope $\lambda/2$. For a frequency '$\nu$' of the sound wave the velocity is given by

$$V=\nu\lambda \tag{5.1}$$

It can be shown that
$$V=\sqrt{\frac{\gamma RT}{M}} \tag{5.2}$$

Where $\gamma = C_p/C_v$, R = 8.31 J.mole$^{-1}$.K$^{-1}$ and M is the molecular weight expressed in kg.mole$^{-1}$. Composition of dry air is 78% $N_2$ and 21% $O_2$ and many other gases (the main other one is Argon with 1%. All these gases are mixed with water vapour, which can rise up to 2% in the final result, depending on temperature and meteorology). $\gamma$#can be calculated using statistical mechanic. It depends on the number n of degrees of freedom. As the 2 main gases are diatomic gases ($N_2$ and $O_2$), diatomic gases value can be assumed for n. Statistical mechanic predicts the following result :

$$\gamma = \frac{n+2}{n} \tag{5.3}$$

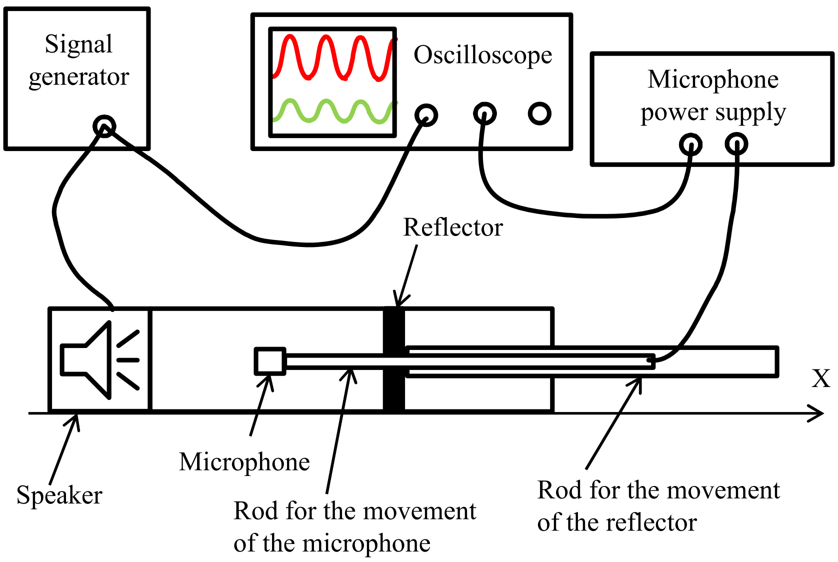



**Figure 5.1** : Experimental setup for Kundt's tube

**4 Experimental setup:** The method used in this experiment is a modern version of Kundt's tube. It consists of a plastic tube with fixed loudspeaker at one end and a microphone (mic) attached to a movable rod at other end. Sound from the loudspeaker produces a standing wave pattern in the tube and is detected by the microphone which is moved in the tube using a rod. The signal from the microphone is viewed using an oscilloscope. An audio signal generator is used to drive the loud speaker. Successive maxima, which are separated by $\lambda/2$, are located by moving the rod and observing the signal on the oscilloscope. For each maximum, a measurement ($y$) is made of the distance between a point on the movable rod and the end of the tube.

**5 Procedures:**

(a) Connect the sine wave output of the signal generator to the speaker. Connect it also in parallel to the first channel of the oscilloscope. Connect the output of the microphone to the second channel of oscilloscope.
(b) Check that the signal on the oscilloscope is sinusoidal, stable and undistorted.
(c) Put the microphone against the reflecting disc.
(d) Tune the frequency on the signal generator to get a signal of maximum from the microphone.
(e) Without moving the reflecting disc, move the microphone along the tube and measure the position of the microphone for each zero of amplitude.
(f) Repeat this measurement for several resonance frequencies.

**6 Result and calculations:**

(a) Plot $y_n$ as a function of n. Is it a straight line? Measure the slope and calculate the wavelength $\lambda$ and hence the velocity V for each frequency. If you have enough time, try to find what the extreme values of the slope are. What errors does it mean for the velocity you have measured?
(b) If you have time, using the least squares method to fit a straight line for $y_n$ vs. n data, calculate the slope. Is it in agreement with what you had previously obtained? Plot the least squares fit line on the same graph paper and check how the experiments data points are placed with respect to the least squares fit line.
(c) Using the formula $V = \sqrt{\gamma RT/M}$, calculate $\gamma$ for each frequency. How do your $\gamma$ value compare with what you would expect for air (M = 29 g.mole$^{-1}$, 0 K = -273 K)? How many degrees of freedom is there for air molecules?

**7 Precautions:**.

(a) For a set of readings, audio signal level should not be changed.
(b) Reduce the amplitude of the generator to the minimum when you are not doing any measurement to avoid useless noise.

# 6-Doppler effect

**1 Aim:** discover the Doppler effect using ultrasound waves

**2 Apparatus :** Trolley rolling on a 2 meter long rail with a speaker and a microphone (mic), audio signal generator, amplifier, oscilloscope, chronometer and frequency counter.

**3 Theoritical results:** theory predicts that, if a moving speaker emits a sound wave at frequency $f_0$, a fixed observer sitting in the axis of the movement receives a wave at a different frequency f, which depends on the velocity of the emitter according to :

$$f = \frac{f_0}{1 + \frac{v_x}{c}} \qquad (1.1)$$

where (Ox) is the axis along which the speaker is moving and $v_x$ the algebric component of the velocity along x. This effect is very common, you experiment it each day when you are waiting on the side of a road and a car passes in front of you : when arriving, the sound is high pitched, when the car goes in front of you, the frequency changes and when it goes away the sound has become low pitched. It can be used for many purposes : measurement of blood velocity in a vein, movement of stars, ...

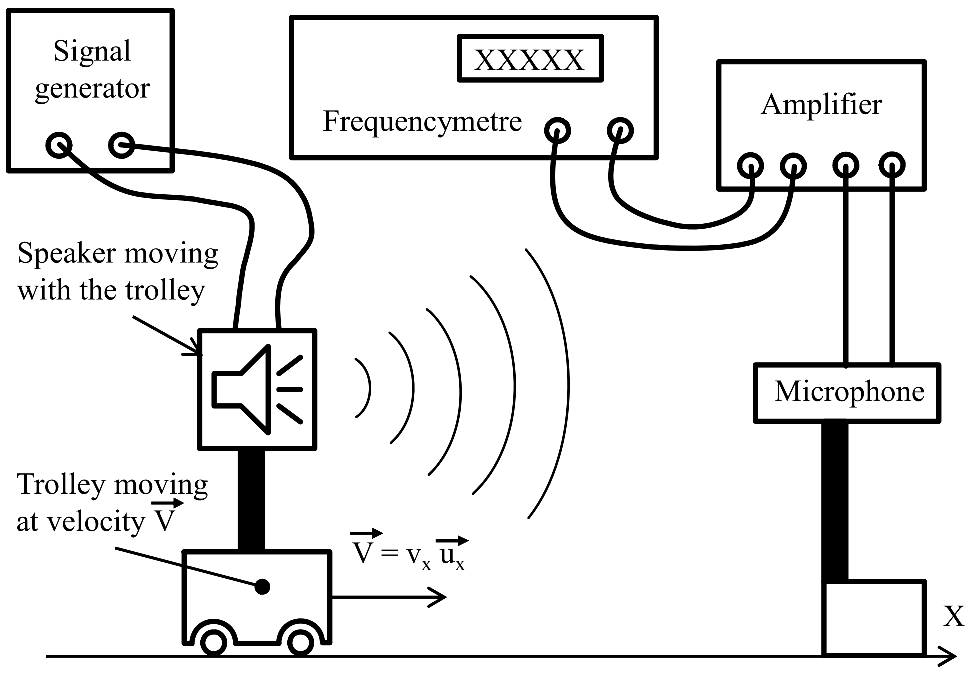



**Figure 1.1** : sketch of the Doppler's setup

**4 Experimental setup:** the speaker is fixed on the trolley. To generate sound, you must connect the speaker to the audiosignal generator. The receiver should be on axis of the rail, some 10 cm away from the end. It should be connected to the amplifier. The output of the amplifier should be connected to the frequencymetre.

**5 Procedure :**

**Preliminary experiment :**

(a) Check that everything is in position (if not, put them into position), trolley should in the middle of the rail. Signal generator should be in continuous mode.
(b) Connect the output of the microphone to the oscilloscope and tune the frequency of the emitter so that the amplitude of the signal on the oscilloscope is maximum. Measure the frequency using the oscilloscope.
(c) Keep the trolley at around 1 m from the microphone. Connect the first input of the oscilloscope in parallel with the speaker, so that you can view what is emitted. Connect the second input of the oscilloscope to the microphone. Put the signal generator in the pulse mode.
(d) Set the two channels of the oscilloscope so that you can see the emitted pulse and detected pulse. Use this to measure the velocity of sound. You can change the position the trolley and see how the two pulses moves on the screen of the oscilloscope.

**Analysis :** What can you deduce from this?

**Doppler effect** :

(a) Put back the signal generator in the DC mode. Remove all connections from the oscilloscope. Connect the output of the amplifier to the frequency counter. Put the frequency counter in the right mode (mode "$f_E$") and the amplifier in the mode ??. Check if the frequencymetre can work all right for the whole range of distance of the trolley.
(b) Put the trolley at one end of the rail, and start the engine using the knob on the trolley. The trolley starts, the frequency changes. Note the extremum frequency observed. Simultaneously, the second student should use the start/stop watch to measure the velocity of the trolley.
(c) Change the direction of the trolley's movement, and repeat the 2 measurements (frequency and velocity).
(d) Change the velocity of the trolley by turning the little black knob on the trolley. Check that the trolley moves almost steadily. Then, repeat the measurements (f) and (g).
(e) Repeat this procedure until you have checked the whole range of velocity possible.

**6 Result and calculations:**

(a) Plot $\Delta f = f - f_0$ as a function of $v_x$, $\Delta f$ and $v_x$ being both algebric (there can be positive or negative depending on case).

(b) Comment the graph obtained. From the theory, what is the law expected for this curve? Does it work? What can be deduced from the slope?

(c) Using the theoritical formula $c = \sqrt{\gamma RT/M}$ , comment your experimental result.

# 7- Perfect's gas law, thermodynamics zero temperature

This lab manual describes how you are going to check the properties of a perfect gas, . The gas studied here is a very common one, it is air.

**Objectives :**

(a) For a constant quantity of gas, at constant temperature, determine how the pressure depends on volume.
(b) For a constant quantity of gas, at constant volume, determine how the pressure depends on temperature
(c) Determine the absolute zero thermodynamics temperature by extrapolating the pressure to zero.
(d) For a constant quantity of gas, at constant pressure, determine how the volume depends on temperature
(e) Determine the absolute zero temperature of the thermodynamic scale by extrapolating the volume to zero

**Principle**

The state of a quantity of **n** moles of an perfect gas is completely described by the measurable quantities pressure, volume and temperature. The relation between these three quantities is given by the general gas law:

$$PV = nRT \qquad (7.1)$$

Where P is pressure, V is Volume, T is temperature, n is the quantity of ideal gas in moles and R is universal gas constant ($R = 8.31\ J.K^{-1}.mole^{-1}$)

If one of the quantities p, V or T remains constant, then the other two quantities cannot be varied independently. For example, at a constant pressure p, for example, Gay-Lussac's relationship states:

$$P = KT \qquad (7.2)$$

**Note** : official units for the volume is the cubic meter (m3), the Kelvin for the temperature (K) and the Pascal for the pressure (Pa, $1\ Pa = 1\ N.m^{-2}$). However, for the pressure, the Pascal is not a pleasant unit for common use, because atmospheric pressure is around $10^5$ Pa. So, many people are using an other unit, which the "bar", its value is : 1 bar = $10^5$ Pa. So that, within the precision required for most use, atmospheric pressure can be considered as equal to 1 bar at sea level.

**Note** : to convince someone about the truth of a law, one very good way is to turn it into a linear law, so that, the plot is a straight line. For example, if the law you want to prove $y(x) = \exp(ax)$, plot $\ln(y)$ as a function of x instead of y as a function of x.

**First experiment** : at constant temperature and constant quantity of gas, check how the pressure depends on the volume

**Apparatus** : big syringe connected to manometer through a tube. A manometer is a device which measures the pressure, it can also be called barometer or pressuremeter, the use of one of this designation depends mainly on the use : for example, for meteorological pressure measurement, usually, one uses "barometer".

**About the manometer** : it is a "vacuum" manometer or a differential manometer. It means measure the difference of pressure between the outside and the inside of your device. To get the absolute pressure, you must add the outer pressure, which is the atmospheric pressure. Here, the average atmospheric pressure is 0.955 bar.

**Procedure** :

(a) Hold the syringe from the edges (if you hold from the main cylinder, you will change the temperature of the inside gas with the heat of your hands)
(b) Put the piston at one position, and hold it so that it doesn't move. For high compression rate or high extension, the force you have to apply can become quite big.
(c) Measure carefully the volume with the ruler on syringe and the pressure with the manometer.
(d) Repeat this for several values of the volume.
(e) Plot PV as a function of P : is it really constant as expected?
(f) In fact, the measured volume V is the volume inside the syringe. To this volume, you must add an other volume $V_0$ which is the volume of the tube and some volume inside the manometer. It means that the real volume of the gas is $V+V_0$, and what should constant is $P(V+V_0)$. The additional volume $V_0$ is unknown. Try to find out how you could plot your experimental results, so that you show in a convincing way that you check such a law and, what's more, you become able to determine $V_0$.
(g) Plot this curve, and determine $V_0$. Is the value of $V_0$ sensible?

**Second experiment** : at constant volume and constant quantity of gas, check how the pressure depends on the volume

**Apparatus** : bottle connected to a Torricelli manometer through a tube, stirring heater, thermometer, big beaker and stand to hold the bottle inside the big beaker.

**Principle of a Torricelli manometer** : it relies on the hydrostatic law, which links the pressure to the height of a liquid column in the setup presented on figure 7.1 :

$$p + \rho g z = cste \qquad (7.3)$$

Applying this formular on the case of figure 6.2, you can get $p_1$ using the following formula :

$$p_1 = p_0 + \rho g \Delta z \qquad (7.4)$$

Reminder : in Hyderabad, at the altitude of 500m above sea level, the average value of $p_0$ is 0.954 bar = $9.54 \times 10^4$ Pa, $\rho = 10^3$ kg.m$^{-3}$ and g = 9.81 m.s$^{-2}$.

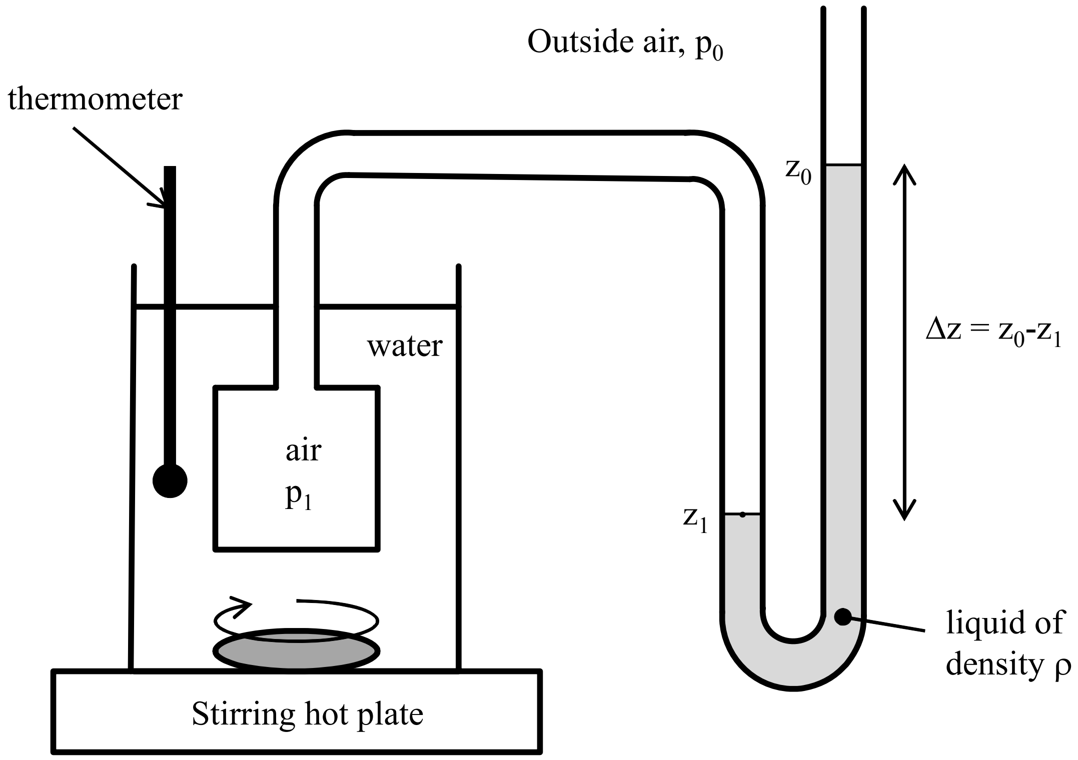



**Figure 7.1** : apparatus for measuring the pressure as a function of temperature, the volume being constant

**Carrying out the experiment**

(a) Fill the big beaker with water, it shouldn't be completely filled, you should keep a little bit more than 500 ml empty.
(b) Put the big beaker on the hot plate. Using the stand, take the empty bottle with the tube and put the bottle inside the water of the big beaker. Connect the tube to the Torricelli manometer.
(c) Start the heating of the hot plate. Due to the increasing temperature the pressure will increase. Stir often the water around the bottle during all the experiment to ensure that the temperature is homogeneous inside the beaker.
(d) With a thermometer inside the water, measure simultaneously the temperature and the pressure (pressure is deduced from $\Delta z$). Do this measurement for each increase of temperature of 2°C.
(e) When the temperature has reached 70°C, stop the heating.
(f) Plot the absolute pressure as a function of the temperature.
(g) For zero pressure, determine by extrapolation what should be the temperature. What is this temperature?

**Third experiment** : at constant pressure and constant quantity of gas, check how the volume depends on the temperature. Let's note that, in this experiment, the volume of gas is given by $V = hS$, where is the height in which there is the trapped gas and S is the section of the tube. You don't know S, but, for you purpose, it doesn't matter :

$$PV = nRT \quad \Rightarrow PhS = nRT \quad \Leftrightarrow \quad h = \frac{nR}{PS}T = KT$$

The aim is to prove that V is proportional to the temperature T if P is constant, which is the same as proving that h is proportional to T, as the section S of the tube is constant. Let's add that, as you don't the value of the constant number of moles of gas, you cannot check the value of the constant in front of T and knowing S would be useless here.

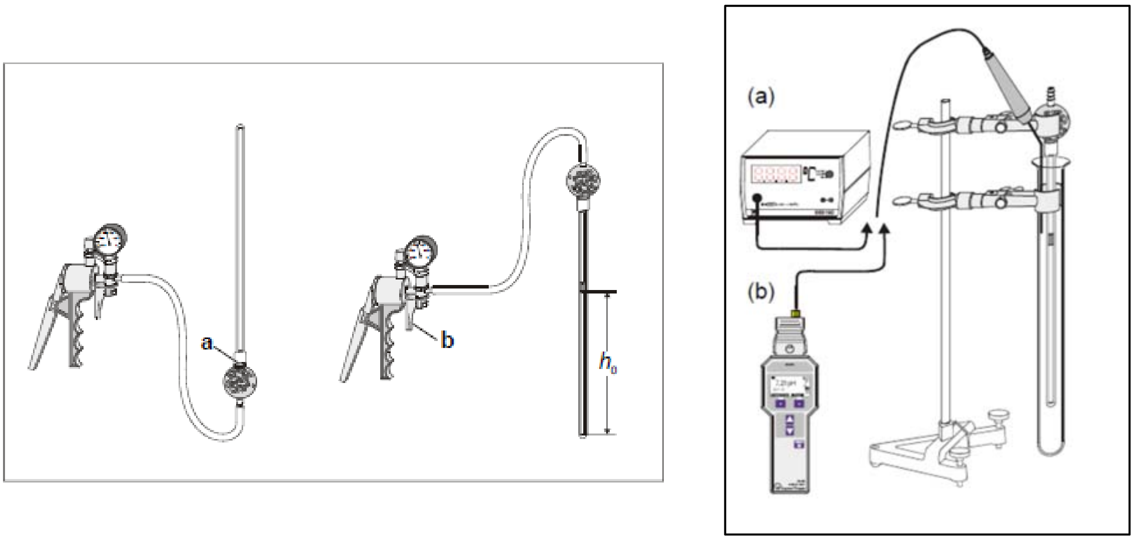



**Figure 6.2** : Collecting the mercury globules and adjusting the initial gas and putting the tube on the stand

**Experimental procedure**

**Collecting the mercury globules**

(a) Connect the hand vacuum pump to the gas thermometer, and hold the thermometer so that its opening is directed downward (see Fig. 2).
(b) Generate maximum underpressure, $\Delta P$ with the hand vacuum pump, and collect the mercury in the bulge (a) so that it forms a drop. The manometer of the hand vacuum pump displays the underpressure $\Delta P$ as a negative value.
(c) If there are mercury globules left, move them into the bulge (a) by slightly tapping the capillary. A small mercury globule which might have remained at the sealed end of the capillary will not affect the experiment.

**Carrying out the experiment**

(a) Heat about 400 ml of water in the saucepan to a temperature of about100°C by means of the hot plate.
(b) Prepare the gas tube, so that the mercury is at 2/3 of the overall height.
(c) Hold the tube vertically and measure carefully the height of the lower end of the mercury droplet.
(d) Check the temperature of the room and start to fill a two-column table with temperature in one of them and height in the other one.
(e) Put the large test tube in position in the stand.

(f) Fill it **very carefully** with almost boiling water, the level of the water should stop 4 cm before the top.
(g) Put the gas tube in position in the stand, inside the large test tube and look carefully at the mercury drop.
(h) Put the thermocouple inside the water of the big tube, in a stable position, so that you can leave it there and you don't have to move it anymore to measure the temperature.
(i) As time goes, the temperature of the water reduces. From time to time, check the temperature and the height of the mercury drop. Add these values in your table.
(j) Plot the height as a function of the temperature.
(k) At what temperature does the volume decreases to zero? determine by extrapolation what should be the temperature. What means this temperature in thermodynamics? Is it possible to cool something at a temperature lower than this temperature?

**Fourth experiment** : it is the Clément-Désormes' experiment. Its aim is to measure the ratio $C_P/C_V$ of a perfect gas. Here, we use air again. The experiment is quite short, it uses a big bottle with 3 inputs :

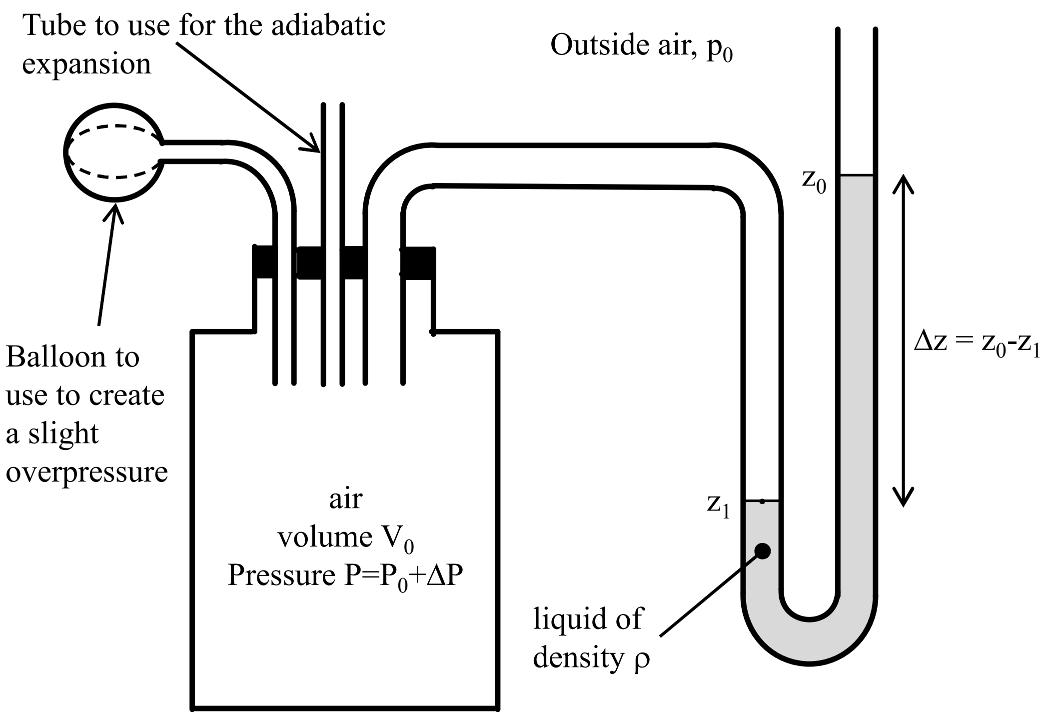



**Figure 7.2** : setup for the Clément-Désormes experiment

**Carrying out the experiment**

(a) Connect the third tube to the U-tube manometer
(b) With your finger close the second tube (expansion tube), you should keep it close during most of the experiment.

(c) With the balloon, inject some air inside the bottle : the pressure should rise.
(d) Close carefully the injection tube with the collar.
(e) Wait two or three minutes : the overpressure should reduce after the injection, until it reaches a steady state.
(f) Measure carefully the initial overpressure $\Delta P_1$ using the U-tube manometer.
(g) When the steady state is reached, open during a short time (no more than a few seconds) the expansion tube, so that pressure inside the bottle goes back to atmospheric pressure. $\Delta z$ should go back to zero. Put back your finger on the end of the expansion tube.
(h) The overpressure should rise back, until it reaches a new steady state. Measure carefully this final overpressure $\Delta P_2$. The experiment is finished, you can let free the expansion tube and take your electronic calculator.

**Theory** :

To make the input, you have to push the gas to send it inside. It means that you are providing some work to the inside gas. According to first principle, the energy of the inside gas has been increased and its temperature has slightly risen above room temperature. When waiting, the gas goes back to room temperature, its quantity (number of moles of gas) and its volume being constant, the overpressure decreases until the gas gets back to room temperature.

When you release the gas, the inside gas experiment an adiabatic expansion and you can apply Laplace's law $PV^\gamma$ = constant :

$$PV^\gamma = \text{constante} \qquad (P_0+\Delta P_1)V_0^\gamma = P_0 V_2^\gamma$$

When you close the expansion tube again, the quantity of gas inside the bottle is reduced, as some of it has been expelled out. The quantity of gas remaining is given by :

$$n_2 = n_1 \frac{V_0}{V_2} \qquad \Rightarrow \qquad \frac{n_1}{n_2} = \left(\frac{P_0+\Delta P_1}{P_0}\right)^{1/\gamma}$$

where $n_1$ and $n_2$ are the number of moles of gas before and after the expansion. Because of the adiabatic expansion, the temperature of the gas has slightly reduced. As the temperature goes back to room temperature, the pressure increases, and you should see $\Delta z$ increasing until it stabilizes at a new height.

Now, applying the law of the perfect gas before and after the expansion, we get :

$$\begin{cases}(P_0+\Delta P_1)V_0 = n_1 R T_0 \\ (P_0+\Delta P_2)V_0 = n_2 R T_0\end{cases} \qquad \Rightarrow \qquad \frac{n_1}{n_2} = \frac{P_0+\Delta P_1}{P_0+\Delta P_2}$$

By equating the two expressions of $n_1/n_2$, we get :

$$\left(\frac{P_0+\Delta P_1}{P_0}\right)^{1/\gamma} = \frac{P_0+\Delta P_1}{P_0+\Delta P_2}$$

As $\Delta P_1$ and $\Delta P_2$ are much smaller than $P_0$, we can use a linear approximation :

$$1+\frac{\Delta P_1}{\gamma P_0} \cong \left(1+\frac{\Delta P_1}{P_0}\right)\left(1-\frac{\Delta P_2}{P_0}\right) \cong 1 + \frac{\Delta P_1}{P_0} - \frac{\Delta P_2}{P_0}$$

At last, extracting $\gamma$, we get : $$\gamma = \frac{\Delta P_1}{\Delta P_1 - \Delta P_2}$$

According to this, what value of $\gamma$ do you get for air? Does it fit with what you have learnt? If there is a difference, how could you explain it?

**Fifth experiment** : it is the Rücchardt's experiment. Its aim is also to measure the ratio $\gamma = C_P/C_V$ of a perfect gas. We are still using air. The principle of the experiment is to study the oscillations of a stainless steel ball in a glass tube mounted on a big bottle of air. The air acts as a spring, and the elasticity constant of this spring depends of the $\gamma$ coefficient, as the compression-expansion of the gas inside the bottle can be considered as adiabatic. The forces acting on the ball are :

- Weight : $-mg\,\vec{u_z}$
- Pressure of the air above the ball, whose value is $P_0$ : $\vec{F_1} = -P_0A\,\vec{u_z}$ (A being the area of the tube section)
- Pressure of the air inside the bottle, whose value is $P = P_0+\Delta P$ : $\vec{F_1} = (P_0+\Delta P)A\vec{u_z}$
- We neglect here the friction on the tube.

Projecting Newton's second law along $\vec{u_z}$, we get :

$$m\frac{d^2z}{dt^2} = -mg+\Delta PA$$

The compression/expansion are assumed adiabatic, $\Delta P$ being small, it can be calculated using the adiabatic compressibility $\chi_S$ defined by :

$$\chi_S = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_S = \frac{1}{\gamma P} \qquad \Rightarrow \qquad \Delta P = -\frac{\Delta V}{\chi_S V} = -\frac{Az}{\chi_S V}$$

The second law of Newton becomes :

$$\frac{d^2z}{dt^2} + \frac{A^2}{m\chi_S V}z = -g$$

Solution is :

$$z(t) = \frac{mVg}{\gamma P_0 A^2}\left[\cos(\omega t) - 1\right] \qquad \text{with} \quad \omega = \sqrt{\frac{A^2\gamma P_0}{mV_0}}$$

From the pulsation, it becomes possible to deduce $\gamma$ : $$\gamma = \frac{\omega^2 mV_0}{A^2P_0}$$

**Procedure :**

(a) Remove very carefully the tube from the top of the bottle and clean it very carefully using the specific cloth and the plastic rod.
(b) If the ball is inside the bottle, get it using the magnet attached to the string.
(c) Put back the tube on the bottle.
(d) Clean neatly the ball with the dedicated cloth.
(e) Have a first try to see what happens : drop the ball from the top of the tube.
(f) Put your finger on the top of the tube, holding carefully the tube, remove it from the bottle, put it above a selected area. Still holding carefully the tube, remove your finger which was sealing the top of the tube : the ball falls on the selected area.
(g) Put back the tube on the bottle.
(h) Clean again the ball with the dedicated cloth.
(i) Prepare the digital oscilloscope for recording the fall. When the spot starts on the left side of the screen, drop the ball. Freeze the screen of the oscilloscope by pressing on the button "Run/stop" before the spot reaches the right side of the oscilloscope.
(j) Measure the period of the movement.
(k) Check the characteristics of the bottle, of the ball, of the tube and calculate $\gamma$.

**Analysis** : comment the result you have obtained.

# 8-Measurement of Specific heat by calorimetric

**Aim:** Measurement of Specific heat by calorimetric

**Theory:** When a material is heated, the internal energy of it increases resulting to a increase in temperature. The heat absorbed by the material is usually characterised by a measurable physical quantity, specific heat capacity or thermal capacity. It is defined by the energy absorbed by the material associated to the resulting temperature change.

There are two types of specific heat capacities of a materials as the transformation can take place either at constant volume (corresponding heat capacity is termed as Heat capacity at constant volume $C_V$) or at constant pressure (corresponding heat capacity is termed as heat capacity at constant pressure. $C_P$)

According to the definition, if a material is supplied with Q amount of heat with the temperature change of $\Delta T$ at constant volume, then the Specific heat of the material at constant volume is proportional to the heat absorbed:

$$Q = C_V \Delta T \quad (8.1)$$

And similarly, $Q = C_P\Delta T$ where $C_P$ is the heat capacity at constant pressure

heat capacities are expressed $J.K^{-1}$. But in practice, we use mass heat capacity of a material which can be defined as the amount of heat energy required to raise the temperature of a body per unit of mass. Mass specific heat capacities are denoted by $c_V$ and $c_P$ respectively, the unit becomes $J.kg^{-1}.K^{-1}$. If m is the mass of the corresponding material, then

$$C_V = mc_V \quad (8.2)$$

$$C_P = mc_P \quad (8.3)$$

**Equipments required to conduct the experiments:**

(a) Electric cables
(b) Voltmeter and Ammeter
(c) Thermometer
(d) Resistance heating immersion
(e) Stop watch
(f) Set of masses of objects identical or different materials and volumes
(g) Balance
(h) Special tweezers to put in or remove from masses from the boiling water

**Experimental procedure:**

**Measurement of specific heat of water:**

(a) Weigh the vessel. Add some water in the calorimetric vessel to fill the vessel, weigh again the vessel with the water. What mass $m_W$ of water have you put in the vessel?
(b) Insert the thermometer, shake well for 15 seconds, then read the temperature on the thermometer.
(c) Plug all the electrical cables for the heating without turning the power supply on. Be careful of how you connect the minus pole of the power supply. Once all the connections are right, turn the power supply on and start simultaneously the stop watch.
(d) Once the power supply is on, measure the voltage V and the current I. During all the process, check the voltage and the current. If necessary, adjust the value of V during the experiment to ensure the constant power input.
(e) Every 1 minutes, stir the liquid for 15 seconds to ensure the homogeneity of temperature and measure the temperature again. Stop simultaneously the power supply and the stop watch when the temperature rise is enough to have a change of temperature of at least 5 C. The heating should be longer than 2 minutes (so that you can measure precisely the duration of the heating with the stop watch and you have time to measure I and V) and shorter than 10 minutes. If after 10 minutes, the temperature rise is still too small, stop the power supply and restart everything with a higher power.

**Calculations:**

If voltage is V and the corresponding current is I and the current is supplied to the system for a period of t, then the energy supplied to the system is

$$Q = V.I.t = m_W c_W \Delta T \qquad (8.4)$$

Where :

$m_W$ is the mass of water used

$c_W$ is the massic specific heat of water

$\Delta T = T_{final} - T_{initial}$ is the temperature change

So: $$c_W = \frac{V.I.t}{m_W \Delta T} \qquad (8.5)$$

**Question** : you want to have a cup of tea, you have a kettle, its heating power is 2kW. You have put inside 0.5 litres of water at room temperature ($T_0$ = 20°C). How long is it to get this water at the boiling point temperature ($T_1$ = 100°C)?

**Measurement of specific heat of solids** :

To measure the specific heat of a solid material (here brass), a different procedure is followed:

The calorimeter is filled with fixed amount of water at room temperature. (Let us assume the temperature to be $T_0$ measured by thermometer)

(a) Fill the calorimeter with cold water, check as before the weight of water put inside.
(b) Take a piece of brass (measure the weight of it before) and, using the special tweezers, dip it into a saucepan filled with boiling water. ☠ : only the tweezers should go iside the boiling water, if you put your hand in the boiling water, you'll very badly burnt. Dip it into the water for a certain time to ensure that the temperature of the metal block reaches upto the temparature of boiling water. Note down the temperaure of the water ($T_1$). Using again the special tweezers, quickly take it out from the water and dry it in the air for few seconds. (don't expand the time otherwise the temperature of the metal block will decrease). Then pour it into the water of calorimeter.
(c) Stir the water continuously monitoring the temperature change until it becomes stable (Note down the temperature $T_F$)
(d) Remove the block of brass from the water and repeat the experiment with other blocks of materials.

**Calculations**:

If the calorimeter is thermally insulated and no energy is assumed to go out, then at equilibrium :

$$m_w c_W(T_F - T_0) + m_M c_M(T_F - T_1) = 0 \qquad (8.6)$$

Where $m_W$ and $m_M$ are the corresponding masses of water and the metal block, $C_w$ and $C_M$ are the massic specific heats of water and metal

So :
$$c_M = \frac{m_W c_W(T_F - T_0)}{m_M(T_1 - T_F)} \qquad (8.7)$$

If you have time, check the heat capacity of brass per mole of atoms. Composition of brass is 30% of zinc and 70% of copper, its density is 8400 kg.m$^{-3}$, the atomic masses are $M_{Cu}$ = 63.5 g.mole$^{-1}$ for copper and $M_{Zn}$ = 65.4 g.mole$^{-1}$.

**Latent heat of ice** :

To melt ice, starting from ice (solid state) at 0°C and turning to liquid water at the **same** temperature, heat must be provided. This heat is called latent heat of enthalpy fusion. The aim is here to measure it. You should have some piece of ice floating in a bucket of liquid water.

(a) Fill the calorimeter with around $m_w \cong 100$ g of room temperature water. Stir well the water with the cap of the calorimeter on and check the temperature $T_0$. All the wiring for the heating resistance should removed.
(b) Check the weight of the vessel with the cap (you don't need in this experiment to fix the cap with the springs, just holding it carefully is enough).
(c) Open the cap, with the tweezers take some piece of ice cube and put it in the calorimeter. Close quickly the calorimeter.
(d) Stir well until the temperature is stable. You can have a quick look inside to check that all the ice has melt.
(e) Write down the temperature $T_1$.
(f) Check the weight of the vessel with the cap. What is the weight $m_{ice}$ of ice put inside the calorimeter?

**Calculations**:

If the calorimeter is thermally insulated and no energy is assumed to go out, then at equilibrium, assuming ice to be at temperature $T_E = 0°C$ :

$$m_{ice}L_f + m_{ice}c_W(T_1-T_E) + m_Wc_w(T_1-T_0) = 0 \qquad (8.6)$$

Where $m_W$ and $m_{ice}$ are the corresponding masses of liquid water the start and of the ice cube, $C_w$ is the massic specific heats of water and metal

So :

$$L_f = \frac{m_{ice}c_W(T_1-T_E) + m_Wc_w(T_1-T_0)}{m_{ice}} \qquad (8.7)$$

It is reminded that $c_w = 4.18$ J.g$^{-1}$.K$^{-1}$. According to the handbooks, at 0°C, $L_f = 334$ J.g$^{-1}$, compare your result to this data. If there is a difference, how can you explain it?

# 9-Thermal conductivity of a bad conductor using Lee's disk method

**1 Aim:** To determine the coefficient of thermal conductivity of a bad conductor.

**2 Apparatus:** Lee's Disk apparatus comprises of a two brass disks 11 cm x 12 mm (Diameter d × thickness x), thermistor $T_1$ and $T_2$, special heating coil, disk shaped poor conductor (glass), gloves, ruler, Vernier calliper.

**3 Theory:** thermal conductivity k is defined by the Fourier's law. According to this law, the heat flowing in a rod of section A and of length x

$$\Phi_{BA} = kA\frac{T_B - T_A}{x} \qquad (9.1)$$

where $T_A$ and $T_B$ are the temperature at the two ends of the rod (here the "rod" is a flat disc, it is a very short rod). Intuitively, this formular is straightforward : the heat flow is proportional to $T_B$-$T_A$, to the section $A = \pi d^2/4$ and inversely proportional to the length x. To all this, a multiplicative coefficient must be added, it is the thermal conductivity k. Unit for k is $W.m^{-1}.K^{-1}$. As x is small, the outside area in contact with the air ($\pi dx$) is small as compared to the large cross sectional area ($A = \pi d^2/4$) of the disc. So, heat flow from the side of the glass disk can be neglected.

To determine k, the setup used here can be described as shown of the figure below.

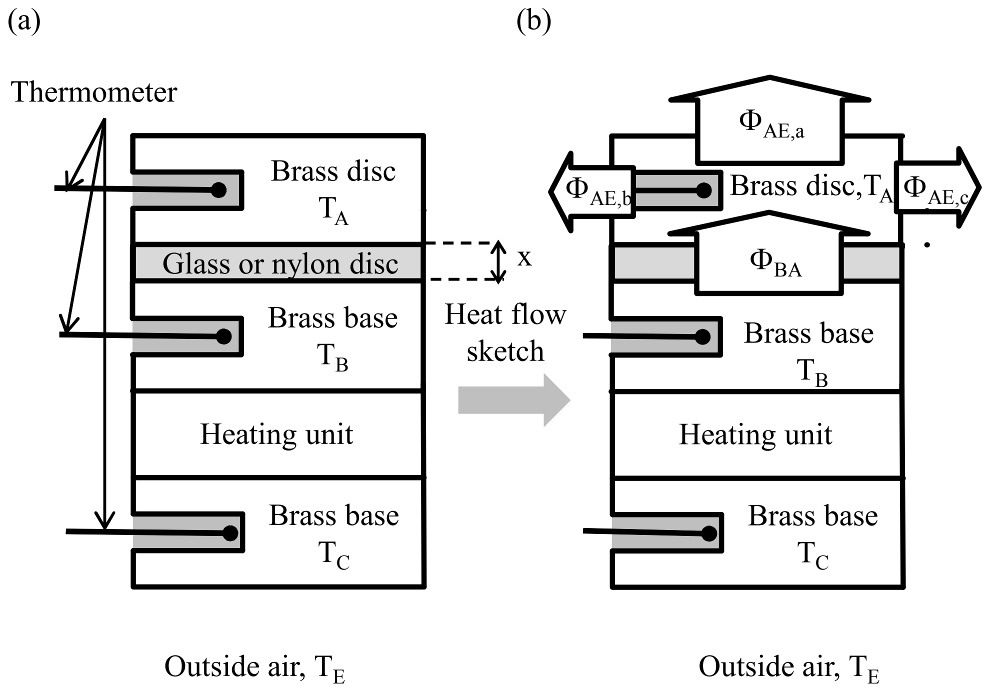



**Figure 9.1 :** (a) sketch of the setup, (b) heat flow in this setup

As there are also heat exchanges between the brass disks and the outside air, the temperature doesn't increase to very high values. The heat flow between the lower bras disk and the outside can be described by :

$$\Phi_{AE} = \Phi_{AE,a} + \Phi_{AE,b} + \Phi_{AE,c} = h\,(T_A - T_E) \qquad (9.2)$$

It is connected to the temperature of this brass disk according to :

$$mc\frac{dT_A}{dt} = \Phi_{EA} + \Phi_{BA} \qquad (9.3)$$

It can be written :

$$mc\frac{dT_A}{dt} = \frac{kA}{x}(T_B - T_A) + h\,(T_E - T_A) \qquad (9.4)$$

**Experimental procedure :**

(a) Check the weight of the brass disc.
(b) Switch on the temperature controller (red switch "Power"). Press "Enter", wait 2 or 3 secondes, then press "Enter" again, wait a few more secondes : the screen should show the four temperatures $T_1$, $T_2$, $T_3$ and $T_4$.
(c) Put the glass disc or the nylon disc on top of the heating system. Put a brass disc on top of the previous disc.
(d) Select "Manual" mode for the heating unit and switch on the heating (black switch).
(e) Every minute, write down $T_1$, $T_2$, $T_3$ and $T_4$.
(f) After half an hour, the temperature of the heating unit should be around 50°C. You can stop recording the temperatures.

**Analysis :**

(a) Plot the temperatures $T_A$ and $T_B$ (according to figure 9.1.a) as a function of time.
(b) For two different times, using your graph, determine $dT_A/dt$, $mcdT_A/dt$ (useful data : for brass $c = 375\ J.g^{-1}.K^{-1}$), $T_E-T_A$ and $T_B-T_A$.
(c) The result is a system of two equations, with two unknown quantities, which are $kA/x$ and h. Get $kA/x$ out of this system and deduce the value of k.

Now the heating unit is hot, and you are going to use another method to measure the heat conductivity of nylon or glass.

**Experimental procedure :**

(a) Put the glass or nylon disc above the heating unit. Put a cold brass cylinder above. To finish put the insulating cap around the upper brass cylinder (see figure 9.2.a). Put the hot brass cylinder in a position where it can cool quickly.
(b) Wait two or three minutes, and start to record $T_A$ and $T_B$ as a function of time. After 8 minutes, you can stop.
(c) Replace the glass or nylon disc by the one you have not studied yet and repeat the procedure.

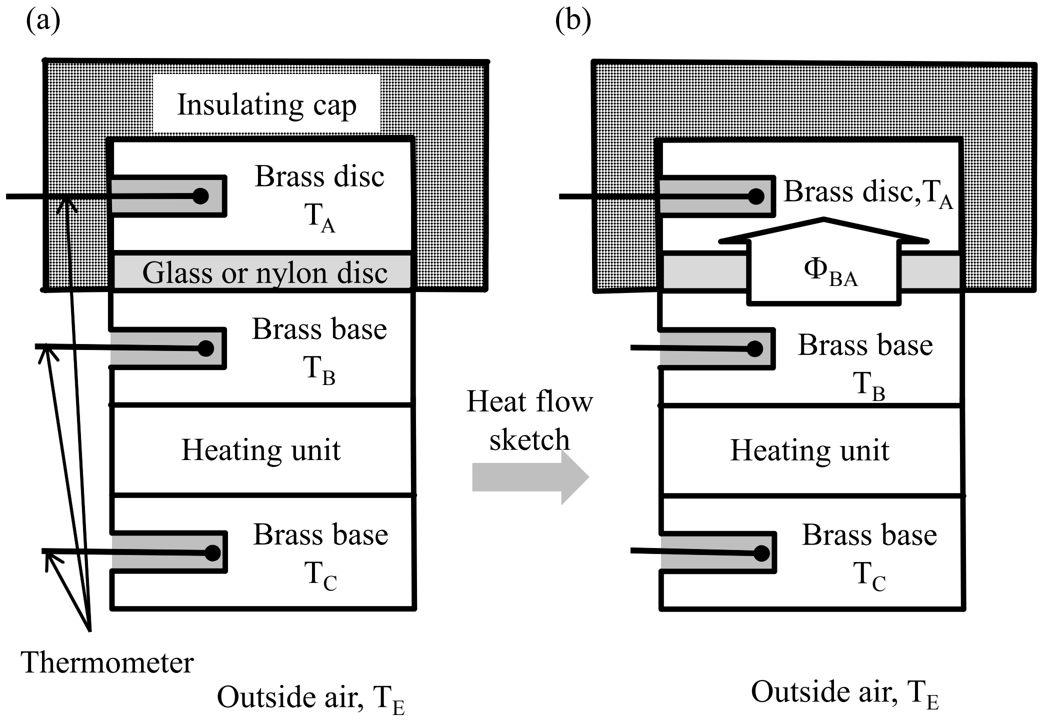



**Figure 9.2** : (a) sketch of the setup with the insulating cap, (b) heat flow in this case

**Analysis :**

Because of the insulating cap, the heat exchange between the brass cylinder and the outside air should become negligible. Than, equation (9.4) becomes :

$$mc\frac{dT_A}{dt} = \frac{kA}{x}(T_B - T_A) \tag{9.5}$$

Plot $T_A(t)$ for nylon and glass. Determine graphically $dT_A/dt$ and deduce k for both materials.

According to you, what should we think of these values? Are the real values within the error bars assuming random noise? Should they be slightly lower or bigger than your experimental values?

# 10-Young's modulus

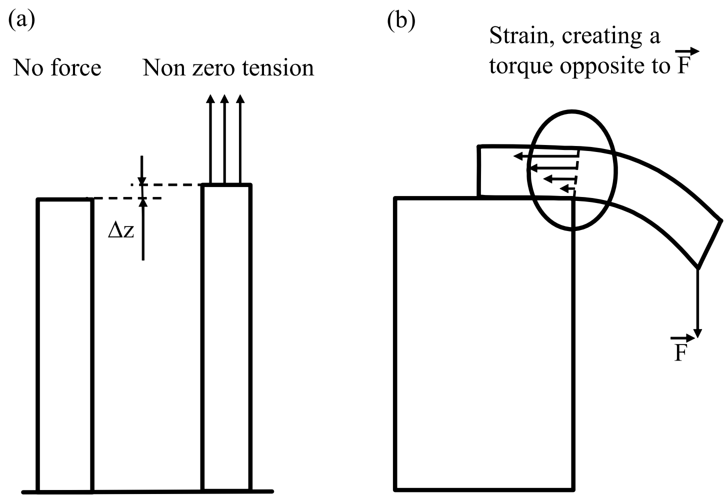
**1 Aim:** when you apply a pressure on a rod, or when you pull it apart, its size changes very slightly (figure 10.1.a). It is so small that most often you cannot see it, but, it is important, because it explains many properties (sound propagation, strain in a solid, ...). In fact, the rod acts as a spring. The elastic properties of this spring depends on the geometry of the rod and on the properties of the material. The relevant parameter is the Young's modulus, which can be defined as :

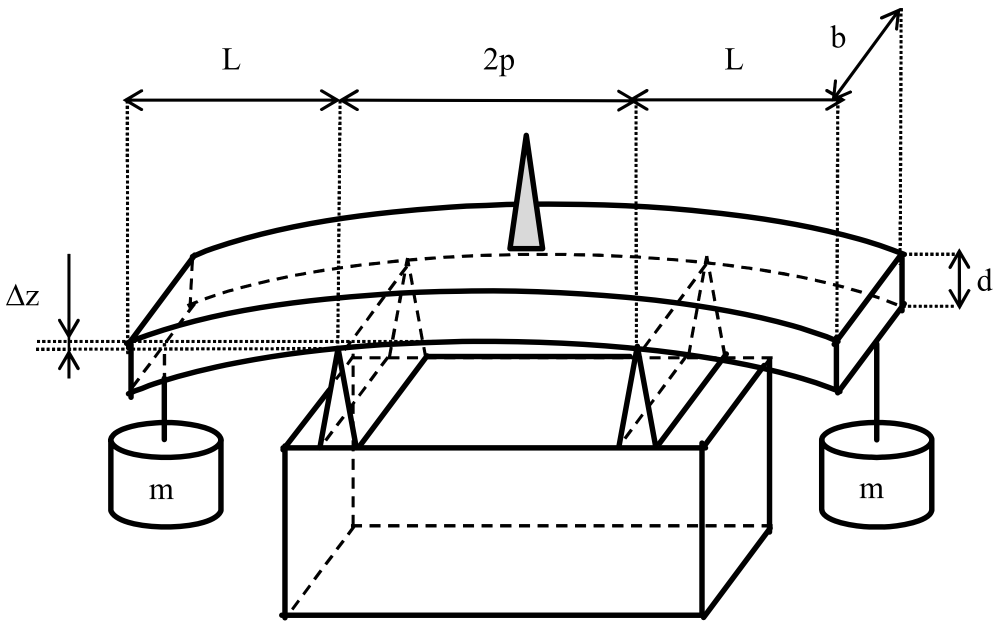
$$E = \frac{\sigma}{\varepsilon} \qquad \text{with} \qquad \sigma = \frac{F}{A_0} \qquad \text{and} \qquad \varepsilon = \frac{\Delta L}{L_0}$$

where F is the force applied, $A_0$ the cross-sectional area of the rod, $L_0$ its length at rest and $\Delta L = L - L_0$. $\sigma$ is called tensile stress and $\varepsilon$ is called extensional strain. The aim is here to determine the Young's modulus of several materials.

**2 Apparatus:** some bars made of several materials, some masses to create stress, two axis mounted on a ruler, a needle acting as pointer and a microscope mounted on measuring screw.

**3 Theory:** as it is very difficult to measure the change of length of a rod, we use a cantilever system in which the displacement is amplified by the geometry. On figure 10.1.b, there is an example of cantilever. Because of the lever arm, the torque induced by the force F is greatly amplified and it requires a very big strain in the sheet at the edge of the table to compensate it. The result is that you can have a meaningful bend of the sheet with a quite small force. Checking this bend, knowing the force applied, it becomes possible to get back the strain, the stress and the Young's modulus.






In the case of the present setup (see figure 10.2), it can be shown the following formula between the different parameters :

$$z = Mg \frac{6Lp^2}{Ebd^3} \qquad (10.1)$$

The purpose of the work is to check this law and deduce the Young's modulus of several materials.

**Procedure :**

(a) Prepare the first bar of material, with the weight holders fixed at the very ends of the bar and the needle in between. You should not put any weight yet, the first measurement must be done with no weight.
(b) Check all the sizes of the bar with a caliper.
(c) Choose the distance L, put the bar in a symmetric position on the setup, the needle should be in the middle of the bar.
(d) Set the microscope so that you can see the top of the needle (note that, as the microscope is inverted, the needle appears to be turned downward).
(e) Set the height of the microscope so that the top of the needle is at the same level as the horizontal line of the reticule of the microscope.
(f) Read the height of the microscope.
(g) Check the weight of the first ballast.
(h) Hold carefully the bar so that it doesn't move and add the first ballast (which means two ballasts, as the geometry is symmetrical and there should the same weight at both end of the bar).

(i) Move the microscope so that the top of the needle gets back at the same level as the horizontal line of the reticule. Measure the new height of the microscope.
(j) Repeat this until you cannot see anymore the top of the needle with microscope or you cannot add ballast.

**Analysis :**

(a) Plot z (position of microscope) as a function of weight.
(b) What should you get? Is it right?
(c) Measure the slope of your straight line and get the Young's modulus.

**Second experiment :** according to formula (10.1), z should depends linearly on $pL^2$.

(a) Choose an average weight, check its value and put it on both end of the bar.
(b) Check the height of the needle as a function of L.
(c) For each value of L, calculate p and $pL^2$.
(d) Plot z as a function of $pL^2$. What should you get? Is it right?
(e) From the slope of the straight of the straight line, check the Young modulus again.

**Next experiments :** repeat the first experiment with some other materials and determine the Young's modulus of as many of them as possible within the duration of this physic's laboratory session.