# XI Iberoamerican Physics Olympiad

**Coimbra, Brazil. September 23-30, 2006-11-03**

## EXPERIMENT 1: Wine hydrometer

**(10 points)**

### OBJECTIVE

Determine the density of a liquid by two different methods, one static and one dynamic.

### INTRODUCTION

In the familiar legend, King Hiero of Syracuse asked Archimedes to determine whether a crown was made of solid gold. Archimedes found the answer without destroying the crown. His reflections led him to discover the law of buoyancy. He is said to have run through the streets of Syracuse shouting Eureka! ... Eureka! (I have found it! ... I have found it!).

Portugal produces excellent wines. To determine the alcohol content of grape must, it is usual to use a device (*wine hydrometer*) based on Archimedes' principle.

### EQUIPMENT

- Large vessel of liquid of unknown density
- Large test tube
- Lead shot
- Vernier calliper
- Stopwatch
- Graph paper
- Scissors
- Balance (shared)

DATA

Gravitational acceleration: $g = (9{,}81 \pm 0{,}01)$ m/s$^2$ Mass of each lead pellet: $m_{Pb} = (0{,}88 \pm 0{,}01)\ g$

PRECAUTIONS:

1 - Do not drop the lead pellets vertically into the test tube: it may break.

2 - Lead is toxic if swallowed.
3 - Keep liquid out of the test tube!
4 - Use the balance in an orderly way, without talking to other participants or causing disturbances.

MEASUREMENTS AND ANALYSIS

**A)** STATIC METHOD:

**1 -** Weigh the empty test tube. Add enough lead pellets to make it float vertically. Record the number of pellets added.

**2 –** Add lead pellets and measure the immersed depth ($h$) as a function of the number added ($n$).

**3 -** On graph paper, plot the immersed depth against the added mass.

**4 -** Use your data to find the liquid density and estimate its experimental error.

**B)** DYNAMIC METHOD:

A cylindrical tube, with substantial lead mass at its bottom, floats vertically, partly above the liquid. In what follows, assume the tube is cylindrical.

**5 -** Show that if the tube is displaced vertically from equilibrium

and released, its motion is simple harmonic, with period given by:

$$T = 2\pi\sqrt{\frac{M_{\text{total}}}{A\rho_{\text{L}}g}}$$

where $M_{\text{total}}$ is the total mass of tube and lead, $A$ its cross-sectional area at liquid level, $\rho_{\text{L}}$ the liquid density and $g$ gravitational acceleration. Neglect frictional forces.

**6 -** Measure the period of vertical oscillations of the tube and lead, choosing its total mass $M_{\text{total}}$. State your chosen mass $M_{\text{total}}$ and measured period $T$, with their errors.

**7 -** Determine the liquid density from your measurements and compare it with the value from the static method. Give one or more physical reasons that could explain any difference between the two values.

## EXPERIMENT 2: Light-emitting diodes (LEDs) and Planck constant **(10 points)**

AIM

The aims are: • Measure the wavelength emitted by an LED; • Determine Planck constant

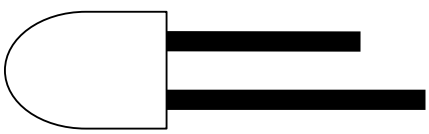
INTRODUCTION Light-emitting diodes, or LEDs (*Light Emitting Diode*), emit light when an electric current flows through them. Electrons move between energy states at the junction of the *n* and *p* regions of the semiconductor. The energy difference is a property of the material. A diode carries significant current only when forward-biased: conventional current flows from the *p* region at higher potential to the *n* region at lower potential. Light is emitted under these conditions. A forward voltage $V$ is applied, and work $W$ is required for an electron to cross the band gap. Most of this work becomes emitted photon energy. Small losses arise from Joule heating and junction processes. For LEDs of the same type **carrying the same current**, these losses are nearly constant. Thus,

$$W = E_{\mathrm{f}} + k \ ,$$

where $E_{\mathrm{f}}$ is the emitted photon energy and $k$ a constant representing other energy losses.

LED light is nearly monochromatic. Changing the semiconductor chemical composition produces different colours. Common LEDs use alloys of gallium, arsenic and aluminium. Varying the proportions of gallium and aluminium gives different visible or infrared wavelengths.

Commercial LEDs have the semiconductor enclosed in plastic and two leads; the longer lead is positive (*p* side).



A diffraction grating can measure the wavelength $\lambda$ emitted by an LED. The angles $\theta_{\mathrm{n}}$ of maximum

diffracted intensity from a grating with line spacing $d$ satisfy:

$$d \sin \theta_n = n\lambda \qquad n\text{: an integer}$$

EQUIPMENT

- Graduated ruler • White paper • Set of LEDs of the same type on a support • 9 V battery • Wires and crocodile clips • Potentiometer (470 Ω) • Resistor (220 Ω) • Resistor (11,4 kΩ) • Two multimeters • Diffraction grating (1000 lines/mm) on a support • Graph paper

DATA:
Elementary charge: $e = 1{,}602 \times 10^{-19}$ C
Speed of light in vacuum: $c = 2{,}998 \times 10^{8}$ m s$^{-1}$
Boltzmann constant: $k_B = 1{,}381 \times 10^{-23}$ J K$^{-1}$

PRECAUTIONS:

1- The current through LED must never exceed 50 mA, or it may be damaged. To protect LED, the 220 Ω resistor **must always be connected in series with LED**.

2- Select suitable multimeter ranges for current or voltage measurement. Incorrect use may blow the internal fuse and hinder completion of the experiment.

INFORMATION

1 - The potentiometer has 3 terminals. The voltage between its centre terminal and either end can be varied from 0 to the battery voltage.

2 - The LEDs supplied have these characteristics:

Table 1:

| LED | λ / nm |
|---|---|
| Blue | 470 |
| Green | ?? |
| Red | 630 |
| Infrared | 950 |

MEASUREMENTS AND ANALYSIS **A)** ELECTRICAL BEHAVIOUR OF LEDs:

Determine the characteristic curve of the red LED: the relation between its current *I* and the voltage *V* across its terminals.

**1 -** Build a circuit applying a variable forward voltage to the red LED. Draw the circuit diagram, including the measuring instruments.

**2 -** Observe the safety limits and obtain the red LED characteristic curve.

**3 -** The *theoretical* relation between current and voltage is:

$$I = I_0 \left( \mathrm{e}^{\frac{eV}{\eta k_\mathrm{B} T}} - 1 \right) \approx I_0 \, \mathrm{e}^{\frac{eV}{\eta k_\mathrm{B} T}}$$

where $I_0$ and $\eta$ are LED-specific constants, $e$ is the elementary charge, $k_\mathrm{B}$ Boltzmann constant, and $T$ ambient temperature (take $T$ = 293 K). This approximation is valid only for $V$ > 50 mV. Above a certain voltage, internal resistance makes the LED depart from this expression. Find $\eta$ and $I_0$ for the red LED.

**4 –** Connect the LEDs in series with one another and with the 11,4 kΩ resistor, then apply 9 V. Crocodile clips may connect the LEDs. State the circuit current and tabulate the voltage *V* across each LED.

**B)** WAVELENGTH OF THE **GREEN** LED:

**5 -** Place the supported diffraction grating before the **green** LED. Check visually for intensity maxima on both sides of the forward direction. Use white paper to

project the diffraction pattern. Determine the green LED wavelength. Describe your procedure, record measurements, and give calculations and the result with its error.

**C)** DETERMINATION OF PLANCK'S CONSTANT, $h$:

**6 -** Use Table 1 and your results from A and B to draw a suitable graph on graph paper for determining Planck constant $h$.

**7 -** Determine Planck constant from this graph. Its value from very precise methods is $h = 6{,}626 \times 10^{-34}$ J s.)