# The 1st Gulf Physics Olympiad — Experimental Competition

**Riyadh, Saudi Arabia — Tuesday, March 22nd 2016**

- The examination lasts for 5 hours. There are 2 problems worth in total 20 points.
- Initially the experimental equipment on table is covered. **You must neither remove the cover nor open the envelope with the problems before the sound signal of the beginning of competition.**
- **You are not allowed to leave your working place without permission.** If you need any assistance (**malfunctioning equipment**, broken calculator, need to visit a restroom, etc), please raise and keep your hand raised until an organizer arrives.
- Use only the front side of the sheets of paper.
- For each problem, there are **dedicated Solution Sheets** (see header for the number and pictogramme). Write your solutions onto the appropriate Solution Sheets. For each Problem, the Solution Sheets are numbered; use the sheets according to the enumeration. **Always mark which Problem Part and Question you are dealing with.** Copy the final answers into the appropriate boxes of the **Answer Sheets**. There are also **Draft** papers; use these for writing things which you don't want to be graded. If you have written something that you don't want to be graded onto the Solution Sheets (such as initial and incorrect solutions), cross these out.
- If you need more paper for a certain problem, please raise your hand and tell an organizer the problem number; you are given two Solution sheets (you can do this more than once).
- **You need to estimate uncertainties only in those cases where you are specifically asked to do so.**
- **You should use as little text as possible:** try to explain your solution mainly with equations, numbers, symbols and diagrams. Though in some places textual explanation may be unavoidable.
- **Do not look into the laser beam or its reflections! It may permanently damage your eyes.**
- **After the signal signifying the end of examination you must stop writing immediately.** Put all the papers into the envelope at your desk. **You are not allowed to take any sheet of paper out of the room.** If you have finished solving before the final sound signal, please raise your hand.

## Problem E1. Rolling cylinder *(7 points)*

**The setup** comprises of 1 a **wooden board** with holes drilled into its one end (the highlighted numbers correspond to the numbers in the fig.), 2 two sticks which can be put through the board's holes; this way one end of the board can be kept in an elevated position, 3 two clamps which can be mounted onto the sticks and will support the board beneath it, 4 measuring tape, 5 stopwatch (press "go" to start measuring, "stop" to record time, and "clear" to reset screen to zero), and 6 a cylindrical bottle with an unknown amount of unknown liquid. You are not allowed to open the bottle (the bottle is secured with a sticker which, once removed, cannot be fixed back).


**Numerical values** for your calculations: **Mass of the bottle (together with the liquid inside)** $M = 50\,\mathrm{g}$. Free fall acceleration $g = 9.81\,\mathrm{m/s^2}$.

**The properties of the liquid inside the bottle depend on temperature. To avoid heating it, keep it in your hands as briefly as possible.**

When the cylinder is put onto an inclined surface, there are four possibilities what can happen.

**A**, if the inclination angle $\alpha$ (the angle between the surface normal and the vertical direction) is very small, $\alpha \le \alpha_0$, it will remain in a resting position.

**B**, for moderately small inclination angles, $\alpha_0 < \alpha < \alpha_1$, the cylinder will roll down with an almost constant speed (if the angle $\alpha$ is very close to the critical value $\alpha_0$, the motion may be slightly uneven: the cylinder almost stops, but shortly after, resumes again rolling motion).

**C**, for $\alpha_1 < \alpha < \alpha_2$, once the cylinder (lying on the surface) is released, it first obtains an *almost constant rolling speed*; this speed is achieved very fast, upon rolling to the distance of the order of the cylinder's diameter. However, that speed will slowly increase during the course of subsequent rolling. The rolling speed grows slowly because the liquid inside the bottle will be smeared around the walls of the bottle (smearing will not take place for $\alpha < \alpha_1$).

**D**, for $\alpha > \alpha_2$, bottle rolls from the beginning to end with an acceleration (rolling with an almost constant speed can never be observed).

### Part A. Critical slopes *(1 points)*

Make measurements to determine the critical slopes $\alpha_0$ and $\alpha_2$. State the values of $\alpha_0$ and $\alpha_2$ (in degrees) together with uncertainties. Note that the measurement of $\alpha_2$ will not be very precise because the crossover from regime **C** to regime **D** is not very sharply defined.

### Part B. Rolling speed *(3 points)*

Fix the board to a certain angle $\alpha$ with $\alpha_0 < \alpha < \alpha_2$ and put the cylinder onto the board near the upper edge of the board; you will be releasing the cylinder from this position during the forthcoming measurements (the cylinder will be rolling downwards). From this position, measure 4 cm downwards, and with a pencil, make a mark onto the boards. Make a next mark to a distance $l = 10\,\mathrm{cm}$ downwards from the first mark. These two marks define the first $= 10\,\mathrm{cm}$-long-segment. When the cylinder starts rolling from the edge of the board, it will obtain a constant speed once reaching the segment. Mark a similar segment close to the lower edge of the board. Release the cylinder from a point near the upper edge of the board; measure and tabulate the data for calculating the rolling speed on both segments, as well as for the average rolling speed over the long segment from the beginning of the upper segment to the end of the lower segment. Based on your measurement data, determine the critical angle $\alpha_1$.

### Part C. Friction force *(2.3 points)*

In order to keep the cylinder rolling with a constant speed $v$, a force $F$ needs to be applied. This force depends on the rolling speed $v$, and on the time $t$ elapsed from the moment when rolling started. So, $F = F(v, t)$. The dependence of $F$ on $t$ is such that at very small values of $t$, $F$ grows, achieves then a maximal value $F_m(v)$, and may slowly decrease later. Based on the measurements of the previous task, calculate and tabulate $F_m(v)$ for different values of $v$. Plot this dependence on a graph, and suggest a formula which describes such a dependence.

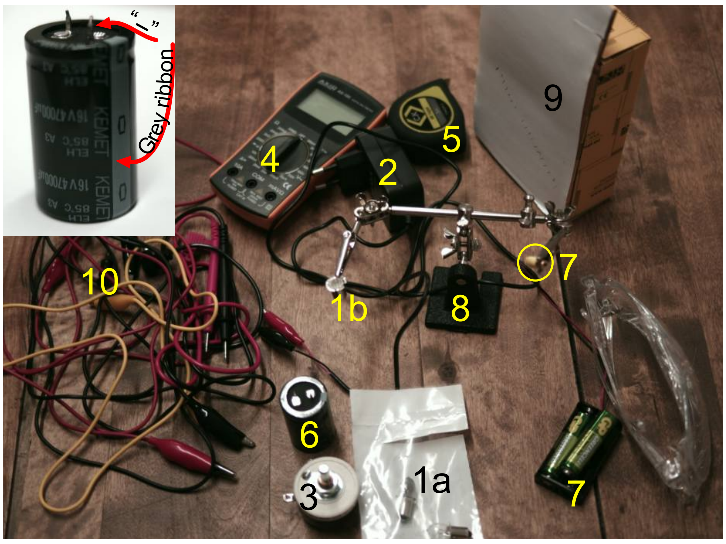
### Part D. Mass of liquid *(0.7 points)*

Based on your measurement data for the previous tasks, estimate the mass of liquid inside the bottle.

## Problem E2. Tungsten filament *(13 points)*

**WARNINGS:**

- **Do not look into the laser beam or its reflections!**
- **Do not connect the electrolytic capacitor in a circuit that can result in reverse polarity on the capacitor! The grey ribbon on it denotes the "minus" side.**
- **Do not short the electrolytic capacitor with the multimeter (in ammeter mode or with the "10 A" connector)!**
- **Use safety goggles while using the electrolytic capacitor (connecting capacitor in reverse polarity may result in an outburst of hot electrolyte)!**




**The setup** comprises of 1a three incandescent bulbs with a tungsten filament which you can consider identical for the purposes of the experiment, 1b one broken bulb without glass, its broken filament is exposed to air (if you need few more bulbs, ask an organizer), 2 power adapter, 3 rheostat, 4 multimeter, 5 measuring tape, 6 electrolytic capacitor, 7 laser with a 3 V battery pack attached, 8 stand, 9 screen (multimeter box with a white paper attached), 10 leads (2 tester leads, 3 banana plug – crocodile clamp leads, 2 crocodile clamp – crocodile clamp leads)

**Numerical values** for your calculations: Wavelength of the laser $\lambda = 650\,\mathrm{nm}$. Density of tungsten $D = 19.25\,\mathrm{g/cm^3}$

Specific resistance of tungsten at room temperature $\rho_{25} = 5.65 \times 10^{-8}\,\Omega\cdot\mathrm{m}$. Function that approximates the temperature of tungsten as a function of its specific resistance fairly well for temperatures between 400 K and tungsten's melting temperature $T_m = 3695\,\mathrm{K}$:

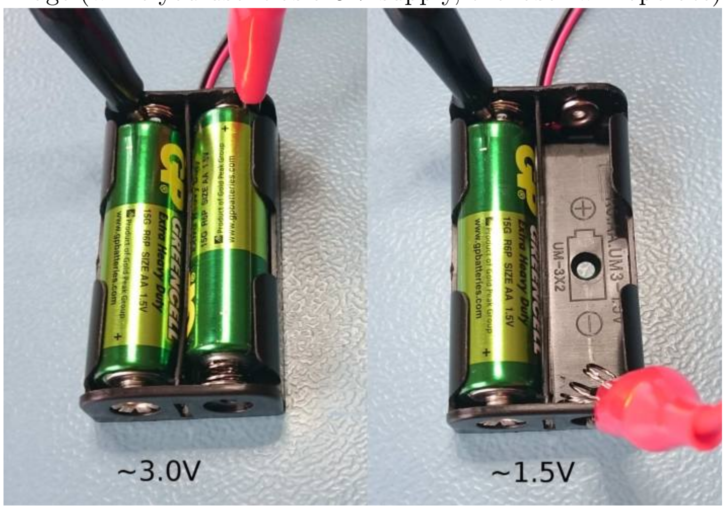
$$T\left(\frac{\rho}{\rho_{25}}\right) = 104\,\mathrm{K} + 216\,\mathrm{K}\cdot\frac{\rho}{\rho_{25}} - 2.46\,\mathrm{K}\cdot\left(\frac{\rho}{\rho_{25}}\right)^2.$$

Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}\,\mathrm{W/(m^2K^4)}$. Capacitance of the electrolytic capacitor $C = 47\,\mathrm{mF}$. Multimeter's uncertainty: as ohmmeter 0.8% + 5 times the last significant digit (LSD), as ammeter (10A) 2% + 5× LSD, as voltmeter 0.5% + 4× LSD.

**Part A. Filament's diameter *(1.5 points)*** Measure the diameter $d$ of the tungsten filament using diffraction. Use the incandescent bulb with exposed filament (the filament has been straightened from its regular coil shape). Sketch the measurement setup. *Hint:* the diffraction pattern from a wire is the same as from a single slit of equal diameter. In order to increase the intensity of the diffraction pattern on screen, focus the laser beam onto the filament by twisting the cap of the laser housing (the laser spot on the screen will be defocused).

If you were unable to determine the diameter, use in what follows $d = 40\,\mu\mathrm{m}$ (which might not be the correct value).

**Part B. Filament's resistance *(2 points)*** Measure the resistance $R$ of the filament at the room temperature **as accurately as possible**. Document the circuit used. Calculate the filament's length $l$. Estimate the uncertainty. You can neglect the resistance of the bulb housing and of the wires supporting the filament. When the multimeter is used for voltage measurements, it can be considered as an ideal voltmeter. **When used as an ammeter, its internal resistance cannot be neglected.** Note that you can use the power supply which provides ≈ 12 V, but if necessary, you can also use the laser battery holder as a 3 V supply or as a 1.5 V supply as shown in the image (while you use it as a 3 V supply, the laser will operate).




**Part C. Current–voltage curve *(2.5 points)*** Plot the current through the bulb as a function of voltage from 0 V until the filament breaks. Document your circuit. What was the maximum temperature $T$ of the filament when it broke?

Note that you can use multimeter in 10 A-range for current measurements; if you do so, you do not have to rebuild the circuit for measuring the voltage: when the multimeter's selector knob is turned between 10 A and voltage measurement positions, the "10A" and COM terminals remain connected inside the multimeter through a resistor of few ohms, and the resistance between the COM and multi-purpose terminals remains very large.

**Part D. Emissivity *(3.5 points)*** Assuming that (a) all of the heat from the filament is dissipated with thermal radiation, and (b) the tungsten filament is a grey body, i.e. its emissivity does not depend on temperature $T$, the Stefan-Boltzmann law predicts that the power dissipation $P = Ak\sigma T^4$, where $A$ is the surface area of the filament and $k$ is the emissivity. Build a graph to verify this prediction. Indicate, for which range of temperatures this prediction holds, and find emissivity of the tungsten filament for that range. At which temperatures the prediction does not hold? Why the prediction fails for these temperatures?

**Part E. Specific heat capacity of tungsten *(3.5 points)*** Measure the quantity of heat $Q$ required to raise the temperature of the filament from the room temperature to its breaking temperature, and calculate average specific heat of tungsten $c$ over this range of temperatures. Document the circuit used. Estimate the magnitude of the main source of error. *Hint:* if you need a voltage higher than 12 V, you can use the power supply and battery pack in series to achieve voltages up to ca 15 V.