"Avaliações Teóricas da Seleção Final para Olimpíadas Internacionais de Física 2018" Brazil Final Selection Theoretical Assessments for International Physics Olympiad 2018

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Problem 1. A free conducting rod moves with constant speed $v = 4\,m/s$ to the right on top of conducting symmetrical tracks. The tracks are connected with a voltmeter VM in one of the edges, with length $d = 4\,m$, and have an opening angle of $\alpha = 16.7\,°$. There is a changing homogeneous magnetic field $B = 1.6\,e^{-v_0\,t/30}\,Wb/m^2$ which points outside the paper as shown in the figure. Answer:

(a) Assuming that at $t = 0$ we have $x = 0$, determine the voltage on the voltmeter as a function of time.

(b) At what time will it reach V_{max} and V_{min}? What is the value of this voltage?

(c) Sketch a graph of the voltage of the voltmeter as a function of time.

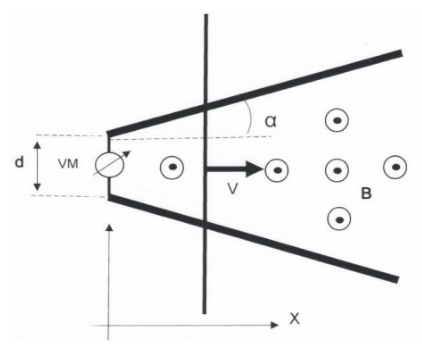


Figure 1: Problem 1

Problem 2. One of the main effects of the gravitational attraction of the Earth-Moon system is the tidal effect. Well known on the surface of the Earth for the variation in the sea level along the lunar month, it also occurs below the crust with the deformation of Earth's magma. Although there is no water on the surface of the Moon, the lunar magma also undergoes deformation due to Earth's gravitational effect. In this problem we're going to analyze how the tidal effect on the Moon connects the rotational speed to the angular motion around the Earth. Initially let the Moon have a rotational speed

ω_0 which is twice the actual rotational speed of the Moon. Let M be the mass of the Earth, $m \ll M$ be the mass of the Moon and R_L be its radius, G be the gravitational constant, R_0 be the radius of the Moon's orbit and T the period of rotation of the Moon in its orbit. In the calculations below, use linear approximations for the appropriate functions. Provide results with 5% accuracy. Disregard the variation of Moon's rotational energy due to the change in its shape.

1. Assuming the Moon takes a circular orbit, determine the radius of that orbit and the potential energy, E_M, of the Moon.

2. To simplify the calculations, suppose that at time t = 0 the entire Moon, including the crust, is transformed into lunar magma, forming a fluid with superficial pressure μ. What happens to the Moon at this instant? Does the mechanical energy of the system remain the same, increase or decrease? Why? Disregard the variation in the position of the Moon's center of mass relative to the Earth.

3. Approximate the ellipsoid to a geometry with three spheres with the same initial density as the moon, the largest having a radius $R_1 = (1 - 2/2187)R_L$ and the two smaller having identical radius R_2. Determine R_2 in terms of R_L. Make a schematic drawing of the Moon model indicating the Earth's position. Where does the energy needed to deform lunar magma come from? Determine that power.

4. Describe the movement that the main axis of the lunar ellipsoid describes during a rotation of the Moon around the Earth. While the main axis describes this movement, the magma keeps itself in rotation around the axis itself, perpendicular to the main axis. Consider that at every rotation there is a constant power dissipation δ. Can δ be different from zero? Why?

5. If your answer was positive, in what situation would the dissipated energy be zero? And how many time would the Moon go around the Earth until it reaching that state?

If the response was negative, determine the difference between the angular velocity of the plasma and that of the main axis of the ellipsoid. Express your results according to the potential energy of the real Moon.

Problem 3. The figure shows an ellipse-shaped object with foci F1 and F2 positioned in a plane that contains the optical axis of a converging lens. Consider it to be translucent or with a slight inclination above the given plane, which allows the existence of rays leaving the illuminated surface which reach the lens and thus form the indicated figure as an image. We have indicated the center of the lens, but neither its angular position around it nor the focal length.

(a) Draw lines in the picture to determine the plane that contains the lens. Indicate it with a segment.

(b) Indicate the focal image point of the lens, i.e. the point where the rays parallel to the optical axis that come from the infinity should meet.

Problem 4. A very small magnet A of mass m is suspended horizontally by an in-extensible string of length $l = 1\,m$. Another magnet B is also very small and is slowly approached to magnet A so that their horizontal axes are always aligned. See graph below. It is noted that when the distance between magnets reaches $d_0 = 4\,cm$, and magnet A is at a distance $s_0 = 1\,cm$ from its initial position, the system remains in equilibrium. However, from this situation a tiny disturbance on the magnet A to the right causes the magnet to move abruptly towards B. Consider that the dependence of the magnetic interaction force on the distance x between the magnets can be written as $F_{MAG(x)} = \pm\frac{K}{x^N}$, where the

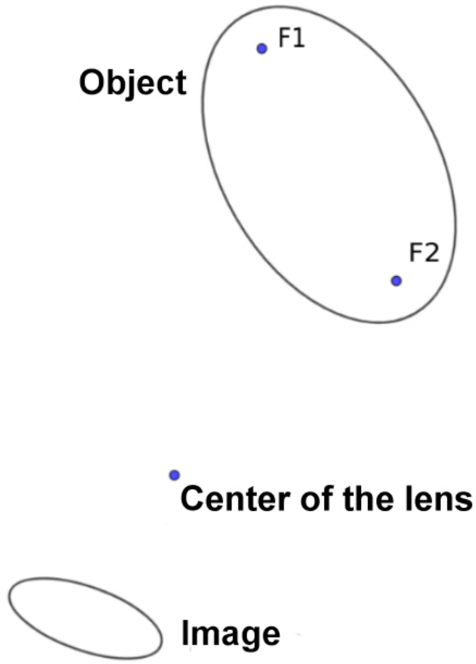


Figure 2: Problem 3

signal depends on the relative orientation of the magnetos. Questions:

(a) Determine and draw on the picture the horizontal forces exerted on the magnet A for a general equilibrium position.

(b) Determine the values of n and K assuming that $g = 10\, m/s^2$ and $m = 10\, g$.

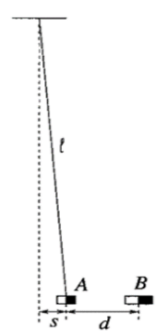


Figure 3: Problem 4

Problem 5. A small conductive bead of mass m and load Q can slide freely without friction onto an insulating and circular thread of radius R. An electric dipole with a very small electrical dipole moment P is fixed in the center of the circle with the dipole's axis in the circle plane in the diagram $\theta = 0$. Initially, the bead is fixed to the dipole's symmetry plane as in the figure below with $\theta = \pi/2$. Disregard the effect of gravity on the movement and assume that the electrical forces are much larger than the gravitational ones. Answer:

(a) Determine the bead's speed after being released from the initial position.

(b) Determine the normal force of the insulating wire on the bead.

(c) At what point in the circle will the bead reach zero speed again after its release?

(d) What would the bead's movement be like if the circular thread did not exist?

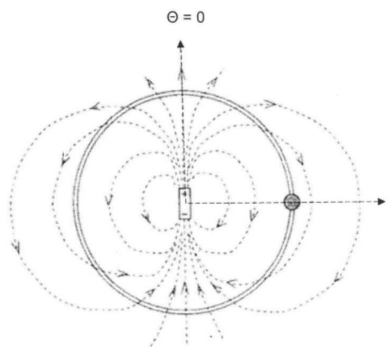


Figure 4: Problem 5

Problem 6. When a metallic filament, such as tungsten, is heated to a high temperature it is observed an emission of electrons from the metal called thermionic emission of metals. This discovery was the basis of all electronics at the beginning of the 20th century with the development of electronic tubes, and even today we find it in various devices such as cathode ray tubes and magnetrons. To observe the thermionic current, the emitting filament (cathode) and the collector (anode) are placed in a vacuum environment to eliminate collisions of electrons with the atoms present in the environment. Under high temperature the emitting filament loses the electrons to the medium, where due to the effect of spatial charge near the filament, an electronic cloud is formed around the filament that eventually inhibits the emission of subsequent electrons. To prevent the formation of this spatial charge cloud, a potential difference is applied between the filament and the collector. The equation that defines the thermionic emission of the filament with respect to its temperature is called the Richardson equation:

$$J_R = A_0 T^2 e^{-\frac{e\phi}{K_B T}}$$

Where J_R is is the current density emitted by the filament, T is the temperature in degrees Kelvin, $A_0 = 3.5 \times 10^4\ A/(m^2K^2)$ and $\phi =$ work function of tungsten $= 4.52\,V$. The temperature T of the filament can be obtained by observing the linear variation of the resistivity with the temperature. The resistance is obtained by monitoring the voltage and current applied to the filament. See figure below. The resistivity of tungsten at room temperature of $270\,°C$ is $5.64 \times 10^{-6}\,\Omega/cm$, the filament has length $l = 6.65\ cm$ and a diameter of $0.018\ cm$. The temperature coefficient of tungsten can be assumed to be $0.004\ K^{-1}$.On the other hand, the equation showing the effect of the accelerator potential between the cathode and the anode for thermionic current is called Child's Law. The collected current density by the anode also depends on the geometry between the two electrodes, the most common being flat or cylindrical. For the case of cylindrical geometry, where the cathode is placed in the center of the cylinder and the anode in cylindrical form, we have:

$$J_C = \frac{4\,\epsilon_0}{9}\sqrt{\frac{2e}{m}}\,V^{\frac{2}{3}} r_a^{-2} \beta^{-2}$$

Where J_C is the current density collected by the anode, V is the voltage difference applied between the cathode and the anode, $r_a = 3.23\,cm$ is the internal diameter of the cylinder, and $\beta = 103.7 \times 10^{-2}$ is the coefficient that depends on the ratio between the radii of the filament. Answer:

(a) Considering that the voltage and current observed on the respective meters in the filament indicate 2.0 V and 1.70 A, determine the temperature of the filament.

(b) For the temperature of the item (a) determine the saturation current you can obtain.

(c) Sketch the linear graph of voltage versus thermionic current observed on the meters of the collector. How can we verify whether the dependencies of these parameters are correct?

(d) How else can we determine the temperature of the filament using the data obtained in this work? And with this result, how can we verify the value of the work function of the filament?

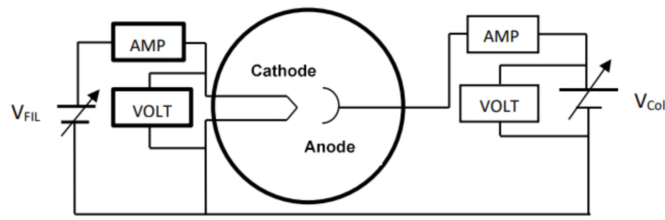


Figure 5: Problem 6

Problem 7. In a photoelectric effect experiment, a known wavelength radiation illuminates an electrode, called cathode (electron emitter), which has working function W_C(energy that an electron inside the cathode needs so that it can beat the electron binding energy in the material). Depending on certain conditions of the incident wave, an electron (photoelectron) can be emitted and advance towards the anode (collector of electrons), which has a work function W_A. The working function of the anode is greater than the of the cathode to avoid the emission of secondary electrons and new photoelectrons (because we are only interested in the photoelectrons emitted by the cathode). The electrical circuit of the experiment is shown in the layout below. In this figure the electrometer measures very low currents, in the order of $10^{-10}\,A$. The multimeter measures the voltage and the DC applied to the two electrodes, and a potentiometer regulates the voltage applied to the electrodes of a battery, generally $\sim 7V$ continuous. To obtain radiation of known wavelengths, we use a mercury (Hg) lamp with a diffraction network to obtain the spectral lines. In the chart below we list the main spectral lines emitted by mercury vapor. Note that the negative side of the source is connected to the anode, in order to repel the photoelectrons when a voltage is applied. And that the voltage observed between the electrodes is different from the voltage applied to the electrodes. And that the work function of the two electrodes must act differently for the photoelectrons. Answer:

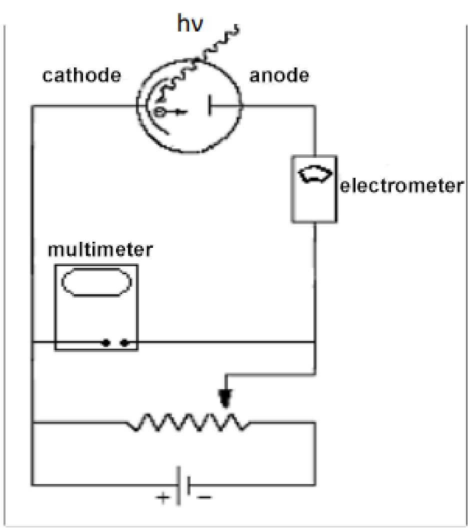
(a) What should be the greatest value of the cathode's work function so that there is emission of photoelectrons for all the colours of the mercury spectra?

(b) Considering that a photon h with the highest energy of the spectra has illuminated the cathode and that it has emitted photoelectrons of a certain energy, write the equation that relates the voltage observed in the multimeter with the other elements of the circuit, such as the wavelength incident on the cathode and any voltage provided by the potentiometer.

(c) Considering the item (b) above, and assuming you are free to adjust the resistance in the potentiometer, explain and discuss in which voltage values we will have a reading of maximum, zero and minimum current in the electrometer?

(d) How can we determine the work function of the anode according to the experimental data obtained in the previous items?

(e) Sketch the current versus voltage curve for an emission spectrum, and discuss what kind of information we can get from this curve.



Photoelectric Effect Layout

Mercury Spectrum (Hg)

Color	Frequency ($\times 10^{14}$ Hz)	Wavelength (nm)
Red	4,34	690,8
Yellow	5,19	578,0
Green	5,49	546,1
Blue	6,88	435,8
Violet	7,41	404,7
Ultraviolet	8,20	365,5

Physical Constants and Conversion Factors

$c = 3{,}00 \times 10^{8}$ m/s
$e = 1{,}60 \times 10^{-19}$ C
$m_e = 9{,}11 \times 10^{-31}$ kg
$m_p = 1{,}67 \times 10^{-27}$ kg
$\varepsilon_0 = 8{,}85 \times 10^{-12}$ F/m
$\mu_0 = 1{,}26 \times 10^{-6}$ H/m
$h = 6{,}63 \times 10^{-34}$ J.s
$R = 8{,}31$ J/mol.K

$k_B = 1{,}38 \times 10^{-23}$ J/K
1 Joule = $6{,}24 \times 10^{18}$ eV = 1×10^{7} erg
1 atm = $1{,}013 \times 10^{5}$ Pa = 760 mmHg
1 bar = 0,1 Mpa
1 torr = 1 mm Hg
1eV= $1{,}60 \times 10^{-19}$ J

Figure 6: Problem 7