CIV Entrance Exam 2018
Physics and chemistry

Length: 3 hours

Examination Center: ____

Candidate's registration number : ☐☐☐☐☐☐☐☐☐☐

Instructions to candidates

- Write above your registration number and the name of the city where you are taking this exam (Astana, Almaty or Chymkent).
- Do not open the examination paper until instructed to do so.
- No calculators, tables or formula sheets may be used.
- Answers should be written in **English or French on the exam paper provided**.
- For each answer indicate the full question number.
- A value without the good unit is considered as false.
- During the exam, if you find a mistake, write it on your paper and explain the changes needed to go on.

BONNE CHANCE / GOOD LUCK !

The parts A, B, C, D and E of this exam are independent of one another.

A - VISCOSITY OF WATER

A spherical grain of sand with a radius $R = 0.050\, mm$, and a density $\rho = 2500\ kg.m^{-3}$, falls vertically into water.

The acceleration of gravity is $g = 10\ m.s^{-2}$. We use a Cartesian coordinate system with the (Oz) vertical axis pointing down, $\vec{u}_z$ being a unit vector on this axis.

This grain of sand is submitted to its weight, the buoyancy force, and a friction force which opposes motion, denoted as $\vec{F} = -6\pi\eta R\vec{v}$ (Stokes formula).

- η is a viscosity coefficient in $Pa.s$ in SI units
- $\vec{v}$ is the velocity vector of the grain of sand : $\vec{v} = v\vec{u}_z$
- Water density is $\rho_e = 10^3 kg.m^{-3}$

A.1 What are the expressions of the weight and the buoyancy force of the grain of sand based on the data?

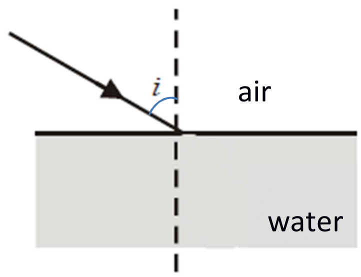
A.2 What is the differential equation satisfied by v? Use the quantity $\tau = \frac{2\rho R^2}{9\eta}$ and $\Delta\rho = \rho - \rho_e$.
What is the dimension of τ? What is its physical significance?

A.3 It is assumed that after about 5τ, the grain of sand reaches a maximum velocity v_∞ . Give the expression of v_∞ as a function of $R, g, \Delta\rho$ and η.

A falling time Δt = 25 s is measured at a fall height of H = 20 cm. Give an estimate of v_∞ and of the value of water viscosity η according to the experiment data.
Finally, explain why it was legitimate to confound the velocity of the grain of sand with its limit value v_∞.

B - REFRACTIVE INDEX OF WATER

The refractive index of water is $n = 1.33 = \frac{4}{3}$



B.1 We consider a horizontal plane dioptre separating air (index 1) above and water (index n) below. A light beam arrives from top to bottom on the dioptre with an incidence i. Draw the refracted ray in the water and give the relation between the refraction angle r and the angle i.

B.2 A pin is planted in the center of a disc shaped cork of radius a (The thickness of the disc is not taken into account). The cork floats on the water, pin down. The cork plug sinks to a negligible depth in the water. The pin protrudes from the cork with a length h. See figure 2 below:

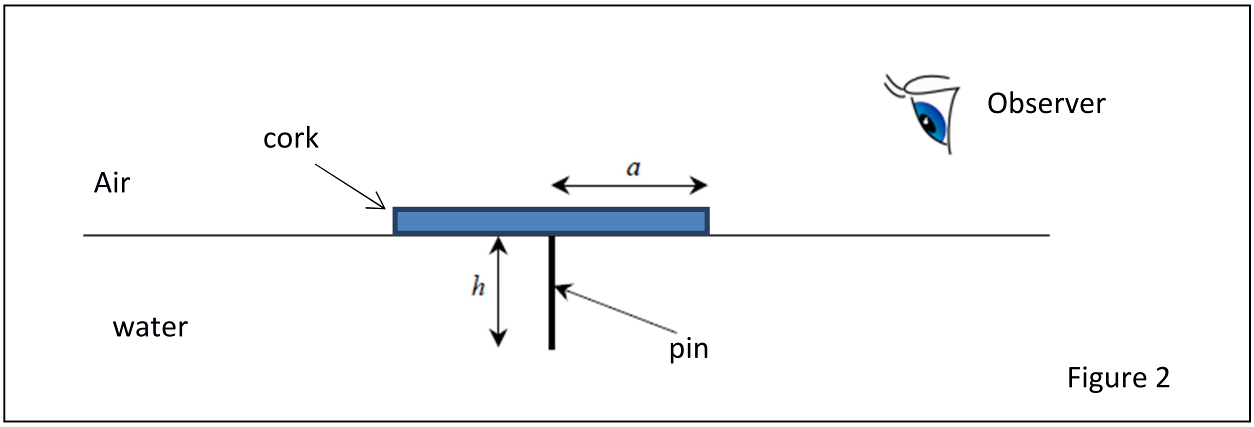


Figure 2

B.2.a An observer looks from above the water. He finds that if *h* is short enough, it is impossible, whatever its position, to see it from the surface. Explain this phenomenon.

B.2.b Calculate the maximum length h_0 of h so that the pin is absolutely invisible from the air. The radius of the disc is $a = 3\ cm$.

Data : $\sqrt{7/9} = 0.9$

$$\frac{1}{\tan^2(x)} = \frac{1}{sin^2(x)} - 1$$

B.3 We seek to measure the refractive index of water using the principle of Pulfrich refractometer. A drop of water is deposited on the upper face of a 90 ° apex angle prism. This drop of water is illuminated by monochromatic light, making sure care that it is also lit in grazing incidence. Using an eyepiece, we observe the emergent radiation from the other side of the prism. See figure 3 below.

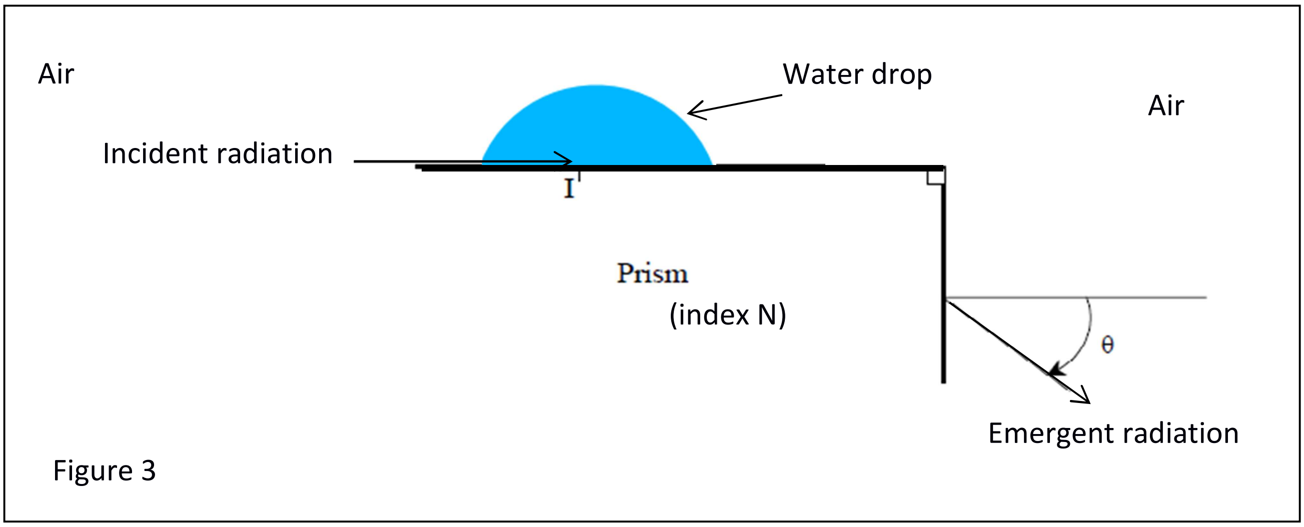


Figure 3

B.3.a The refractive index of the glass constituting the prism is $N = 1.625$. Draw the path of the light ray refracting in I.

B.3.b The angle θ of the emerging ray corresponding to the grazing incidence ray is measured (See figure 3). What is the expression of θ as a function of n and N?

B.3.c What is the maximum value of the refractive index of a liquid that can be measured with this refractometer?

C - HEAT CAPACITY AND MELTING HEAT OF WATER

In this part, we propose to carry out several calorimetric studies. To do this, we have a calorimeter (a supposed thermally insulated container). At first we want to determine its heat capacity K.

We have the following equipement :

- A calorimeter of heat capacity K provided with its stirrer
- a 0.1 ° C precision thermometer
- a 200 mL measuring cylinder with a precision of 2 mL
- tap water
- a kettle or other water heater device

In all experiments, the pressure is considered constant and equal to $1.013\ bar$.

C.1 We use a blending (mixing) method to estimate the heat capacity of the calorimeter. We mix in the calorimeter $m_2 = 200\ g$ of water at a temperature $\theta_2 = 40.0\ °C$ with $m_1 = 200\ g$ of water at a temperature $\theta_1 = 20.0\ °C$. The common equilibrium temperature is $\theta_f = 29.1\ °C$.
Water density is $\rho_e = 1.0.10^3 kg.m^{-3}$.

C.1.a $c_e = 4187 J.°C^{-1}.kg^{-1}$ designates the specific heat of water.
Considering the different heat exchanges, establish the expression of K according to the following data : $m_1, m_2, c_e, \theta_1, \theta_2$ and θ_f.

C.1.b What are the value and the dimension of K ? The dimension of K will be given according to the dimension of energy [E].
Data : $4187 \times \left(1 + \frac{(29.1-40)}{(29.1-20)}\right) = 830$

C.1.c Identify sources of error and estimate the measurement uncertainty associated with the protocol.

The expected value for K (manufacture data) is $150\,J.°C^{-1}$. Is the measure acceptable? Suggest an explanation for the observed discrepancy.

C.2 We apply the same method but this time we add $m_3 = 40\,g$ of ice at a temperature $\theta_3 = 0°C$. The calorimeter of heat capacity K is filled with $m_1 = 200\,g$ of water at a temperature $\theta_1 = 20\ °C$. The common equilibrium temperature (after the ice has fully melted) is $\theta_f = 5\,°C$.

C.2.a L designates the melting heat of ice.
Considering the different heat exchanges, establish the expression of L according to the following data : $m_1, m_3, c_e, \theta_1, \theta_3, \theta_f$ and K.

C.2.b What is the dimension of L ?
The numerical value of L calculated with the experimental values is 328

C.2.c Temperatures are always measured to within 0.1 ° C, volumes to 2 mL and ice to the nearest 1 g.
The expected value for L is $334\,kJ.kg^{-1}$. Is the measure acceptable?
Data : $\frac{6}{334} = 1.8$

D - ELECTROMAGNETIC BRAKING

Maths notation :
Let f be a function of the variable t. f'(t) or $\dot{f}(t)$ or $\frac{df}{dt}$ denotes the derivative of f with respect to t. It is the rate of change of function f at time t.

We work in a Galilean reference frame, linked to the direct orthogonal coordinate system (Ox, Oy, Oz) with orthonormal basis $(\overrightarrow{e_x}, \overrightarrow{e_y}, \overrightarrow{e_z})$.
A conducting horizontal rectangular frame ABCD, with length AD = BC = a and width AB = CD = b has an electrical resistance R. This frame has a mass m, and can move without friction on (Ox) axis in the (Oxy) plan. x is the abscissa of the bar AB.
A time independent magnetic field $\vec{B} = B_0.\overrightarrow{e_z}$ is applied in the domain x ≥ 0, with $B_0 \geq 0$.
In the domain x <0, $\vec{B} = \vec{0}$.
The frame is initially in the domain x < 0, its movement is rectilinear and uniform with velocity $\overrightarrow{v_0} = v_0.\overrightarrow{e_x}$ (v_0 > 0).
At t = 0, we have x(t=0) = 0 and v(t=0) = v_0 with v(t) = $\dot{x}(t)$ the velocity of the bar AB.

Reminders :
- The electromotive force (e.m.f) e(t) is given by the expression : e(t) = $-\frac{d\phi}{dt}$ where ϕ is the magnetic flux.
- When a wire of length L carrying an electric current (i) is placed in a magnetic field ($\vec{B}$, orthogonal to wire) it experiences a force sometimes called the Laplace force $\vec{F}$, with a value F = i.L.B.

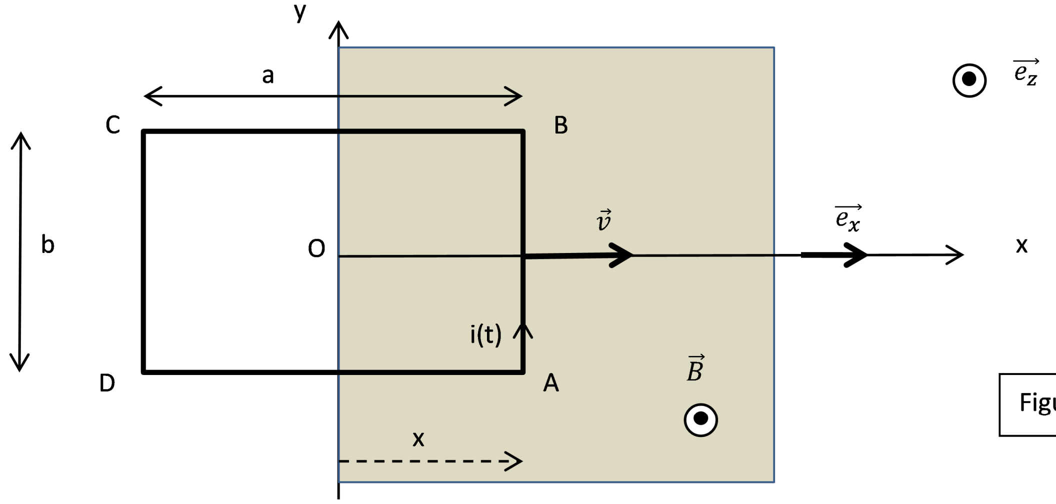


Figure 1

D.I. Analysis of the induction phenomenon

D.I.1 What is the expression of the magnetic flux $\phi(x)$ through the frame ABCD when $0 \leq x \leq a$?

D.I.2 What is the expression of this flux when $x > a$? When $x < 0$?

D.I.3 What is the value of the e.m.f e(t) in the frame when $x < 0$ and when $x > a$?

D.I.4 What is the expression of e(t) when $0 \leq x \leq a$, as a function of B_0 , b and the velocity v(t) of the bar AB ?

D.I.5 An induced current i(t) is thus created. It is equivalent to the one which would be created by a voltage generator of e.m.f e(t) (with the same sign), inserted in the circuit according to the following figure :

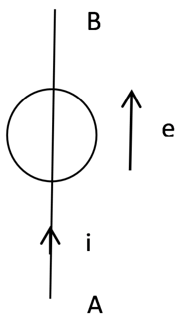


Figure 2

From now on, $0 \leq x \leq a$.

Use a diagram to set up a model for the electric circuit, equivalent to the frame ABCD of resistance R and taking into account the induction phenomenon.

D.I.6 What is the relation between the induced current i(t) and the velocity v(t) of the frame ? What is the sign of this current i(t) ?

D.II. Study of the movement of the frame

D.II.1 Do we have to take gravity force into account in this study ?

D.II.2 What are the different forces acting on the frame while it's in motion ?

D.II.3 Copy figure 1 and draw the Laplace forces $\overrightarrow{F_{AB}}$, $\overrightarrow{F_{BC}}$, $\overrightarrow{F_{CD}}$ et $\overrightarrow{F_{DA}}$ that apply on each side of the frame. Justify your answer.

D.II.4 Express the Laplace resulting force $\vec{F}$, as a function of b, B_0 and i(t). Give the properties of this force. Interpret the result in connection with Lenz's law.

D.II.5 Using Newton's 2nd law of motion, demonstrate that the motion of the frame is governed by the differential equation: $\frac{dv}{dt} + \frac{v}{\tau} = 0$. Give the expression of the constant τ as a function of m, R, b and B_0. Give the dimension of τ.

D.II.6 Check that the solution to this equation is written v(t) = $v_0.e^{-\frac{t}{\tau}}$ and give the expression of the position x(t) of the bar AB. Draw graphs representing the variations of v and x as a function of time t. Comment on the graphs.

D.II.7 We have the following values: v_0 = 1.0 $m.s^{-1}$, m = 100 g, R = 5Ω, b = 20 cm and B_0 = 0.5 T. Give a numerical estimate of the order of magnitude of the frame braking time.

D.II.8 In which form is the energy of the frame dissipated while braking ? Let's assume the frame is immobilised (v(t → +∞) = 0). Give the expression and the value of the dissipated energy.

E - FUEL CONSUMPTION OF A CAR

A car drives at 130 $km.h^{-1}$. The power of its engine is 60 ch.
Fuel in the tank is liquid octane C_8H_{18}, with a density ρ = 720 $kg.m^{-3}$.

E.1 What is, in gaseous phase, the chemical equation for the combustion of octane with oxygen (O_2) ?

E.2 What is the standard enthalpy of reaction Δ_rH^0 for the combustion of octane ?

E.3 Give the value of fuel consumption per 100 km.
Carefully explain your approach and give the result with one significant figure.
The engine efficiency is: η = 0.5.

Data :

1 ch = 736 W
Standard enthalpy of formation values ($kJ.mol^{-1}$) (standard state) :
$\Delta_fH^0(C_8H_{18, g})$ = -230, $\Delta_fH^0(O_{2, g})$ = 0, $\Delta_fH^0(CO_{2, g})$ = -390, $\Delta_fH^0(H_2O, _g)$ = -240
Molar mass values ($g.mol^{-1}$) : M(C) = 12, M(H) = 1
736 x 46 x 60 = 2.10^6
2.10^6 x 114 x $\frac{1}{5050.10^3}$ = 46