CAP High School Prize Exam

6 April 2009
9:00 – 12:00

Competitor's Information Sheet

The following information will be used to inform competitors and schools of the exam results, to determine eligibility for some subsequent competitions, and for statistical purposes. Only the marking code, to be assigned by the local examination committee, will be used to identify papers for marking.

Marking Code:

This box must be left empty.

PLEASE PRINT CLEARLY IN BLOCK LETTERS.

Family Name:________________________________ Given Name:________________________

Home Address:____

____ Postal Code:______________

Telephone: (   )____________________ E-mail: __________________________________

School: ____ Grade:_____

Physics Teacher: ____

Date of Birth: ____________________________ Sex: Male ☐ Female ☐

Citizenship: ____ or

Immigration Status:____

For how many years have you studied in a Canadian school? ____________________________

Would you prefer the further correspondence in French or English? _______________________

Sponsored by:

Canadian Association of Physicists
Canadian Chemistry and Physics Olympiads

Canadian Association of Physicists
2009 Prize Exam

This is a three-hour exam. National ranking and prizes will be based on a student's performance on sections A, B, and C of the exam. Performance on the questions in part A will be used to determine whose written work in parts B and C will be marked for prize consideration by the CAP Exam National Committee. The marking scheme is: 40% for part A, 10% for part B, and 50% for part C. Part A consists of twenty multiple-choice questions; part B consists of five questions that require graphic solution. The problems in part C can also require graphing. The questions in part C have a range of difficulty. Do be careful to gather as many of the easier marks as possible before venturing into more difficult territory. If an answer to part (a) of a question is needed for part (b), and you are not able to solve part (a), assume a likely solution and attempt the rest of the question anyway. No student is expected to complete this exam and parts of each problem may be very challenging.

Non-programmable calculators may be used. Please be careful to answer the multiple-choice questions **on the answer card/sheet** provided; most importantly, write your solutions to the three long problems on **three separate** sheets as they will be marked by people in different parts of Canada. Good luck.

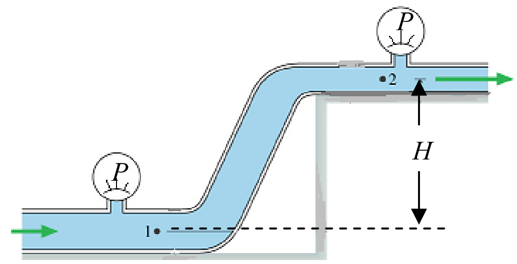
Data

Speed of light $c = 3.00 \times 10^8$ m/s
Gravitational constant $G = 6.67 \times 10^{-11}$ N·m^2/kg^2
Acceleration due to gravity $g = 9.80$ m/s^2
Density of fresh water $\rho = 1.00 \times 10^3$ kg/m^3
Specific heat capacity for water $c = 4.19 \times 10^3$ J/(kg·K)
The normal atmospheric pressure $P_0 = 1.01 \times 10^5$ Pa
Fundamental charge $e = 1.60 \times 10^{-19}$ C
Mass of electron $m_e = 9.11 \times 10^{-31}$ kg
Mass of proton $m_p = 1.67 \times 10^{-27}$ kg

Part A: Multiple Choice

Question 1
A ball falls to the earth from a height h and bounces to a height h'. Momentum is conserved in the ball-earth system:
(a) no matter what height h′ the ball reaches.
(b) only if h′ < h.
(c) only if h′ = h.
(d) only if h′ > h.
(e) only if h′ ≥ h.

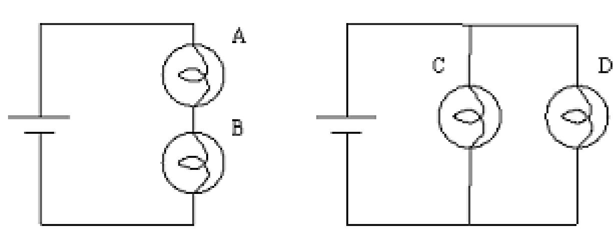
Question 2
A tap water pipe is bent as shown in the diagram. Sections 1 and 2 of the pipe are horizontal but section 2 is placed higher at a height of H. The diameter of the pipe of section 1 is 1.5 times larger than the diameter of section 2. Indicate which of the following is the most complete answer for the relationship between the hydrostatic pressures measured by the gauges in sections 1 and 2:



(a) $P_1 < P_2$ because water flows slower in section 1.
(b) $P_1 > P_2$ because water flows slower in section 1.
(c) $P_1 > P_2$ because section 1 is lower than section 2.
(d) $P_1 > P_2$ because water flows slower in section 1, and section 1 is lower than section 2.
(e) For some value of H, $P_1 = P_2$ because the lower speed of the flowing water in section 1 is compensated by the hydrostatic pressure due to the difference H in the height of the two sections.

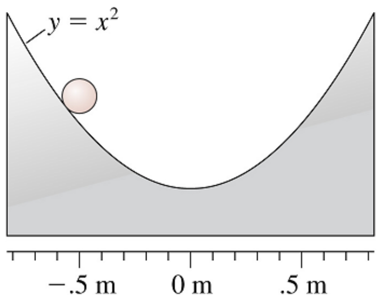
Question 3
We know that a person emits about 500 W of radiation. We also know that a person sitting still uses about 100W of chemical energy. Where is the rest of the energy mainly coming from?
(a) Heat conducted from the air into our body.
(b) Convection of the heat.
(c) Radiation from objects around us.
(d) The energy, emitted by the body does not have to have a source.
(e) Burning fat that we have accumulated previously.

Question 4



In the two circuits shown above, the batteries are identical and maintain constant voltage. The light bulbs A, B, C and D, are identical and have resistance R. Assume that the bulbs are brighter when there is more current flowing through them. Which of the following relationships correctly describe the brightness of the bulbs?
(a) A = B > C = D
(b) C = D > A = B
(c) A = B = C = D
(d) A = C > B = D

Question 5

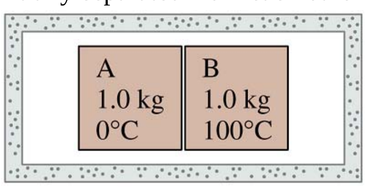


The figure shows an accelerometer: a device for measuring the horizontal acceleration of cars and airplanes. The device consists of a ball that is free to roll on a parabolic track. A scale along the bottom is used to measure the ball's horizontal position x.
What is the acceleration of the car in m/s^2 when the displacement of the ball in the accelerometer equals 0.20 m?

(a) 3.9
(b) 3.6
(c) 26.5
(d) 24.5
(e) 9.1

Question 6

Objects A and B that are initially separated from each other and well isolated from their surroundings are then brought into thermal contact. Initially T_A= 0C and T_B = 100C. The specific heat of A is less than the specific heat of B. After some time, the system comes to an equilibrium state. The final temperatures are:



(a) $T_A = T_B > 50^oC$
(b) $T_A > T_B > 50^oC$
(c) $T_A = T_B < 50^oC$
(d) $T_B > T_A > 50^oC$
(e) $T_A = T_B = 50^oC$

Question 7

An object is moving at a constant speed v_0 towards a source that is at rest and that is emitting sound waves of frequency f_0. The frequency of the echo that returns to the source after being reflected from the object is given by:

(a) $$f_{echo} = f_0 \frac{v}{v - v_0}$$

(b) $$f_{echo} = f_0 \frac{v - v_0}{v + v_0}$$

(c) $$f_{echo} = f_0 \frac{v + v_0}{v - v_0}$$

(d) $$f_{echo} = f_0 \frac{v + v_0}{v}$$

Question 8

An astronaut lifts off from planet Zuton in a spaceship. The free-fall acceleration on Zuton is four times less than on the Earth. At the moment of liftoff the acceleration of the spaceship is 2.45 m/s^2 (up). The weight of the astronaut at that instant is more than her weight on the surface of the earth by the factor of:

(a) 4 (b) 2
(c) 1 (d) 0.5
(e) 0.25

Question 9

A 0.50-kg mass attached to the end of a string swings in a vertical circle with a radius of 2.0 m. When the string is horizontal, the speed of the mass is 8.0 m/s. What is the magnitude of the force of the string on the mass at this position?

(a) 16 N
(b) 17 N
(c) 21 N
(d) 11 N
(e) 25 N

Question 10

What is the velocity of an electron that passes without being deviated through perpendicular electric and magnetic fields if E = 4.0 kV/m and B = 8.0 mT?

(a) 32 m/s
(b) 500 km/s
(c) $2\text{x}10^{-6}$ m/s
(d) 500 m/s
(e) 2 km/s

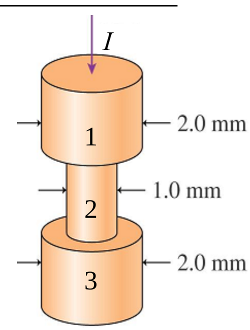
Question 11

A body that is oscillating harmonically in the vertical direction is suspended from two identical springs connected in series. The frequency of oscillation is f_1. After the springs are disconnected and attached to the body in parallel, the frequency of the vertical oscillation of the body is equal to:

(a) f_1
(b) $2 f_1$
(c) $f_1 /4$
(d) $4 f_1$
(e) $f_1 / 2$

Question 12

A piece of aluminum wire shown on the drawing is connected to a circuit with a source of constant current. Choose the correct conclusion on the values of the current (I), the amount of heat (P) emitted per second by a unit of length, and the electric field strength (E) inside the segments of the wire:



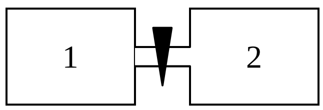
(a) $I_1 = I_2 = I_3$; $P_1 = P_2 = P_3$; $E_1 = E_2 = E_3$.
(b) $I_1 = I_3 = ½ I_2$; $P_1 = P_3 = 1/16\ P_2$; $E_1 = E_2 = E_3$.
(c) $I_1 = I_3 = ½ I_2$; $P_1 = P_3 = 1/16\ P_2$; $E_1 = E_3 = ½ E_2$.
(d) $I_1 = I_2 = I_3$; $P_1 = P_3 = ¼ P_2$; $E_1 = E_2 = E_3$.
(e) $I_1 = I_2 = I_3$; $P_1 = P_3 = ¼ P_2$; $E_1 = E_3 = ¼ E_2$.

Question 13

A spacecraft of mass m orbits a planet of mass M in a circular orbit of radius R. What is the minimum energy required to send this spacecraft to a distant point in space where the gravitational force of the planet on the spacecraft is negligible?

(a) $GmM/(4R)$
(b) GmM/R
(c) $GmM/(2R)$
(d) $GmM/(3R)$
(e) $2GmM/(5R)$

Question 14

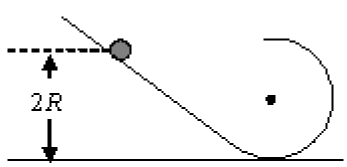


Two identical thermally isolated containers are separated by a valve. Initially, there is an ideal gas in container 1, and there is a vacuum in container 2. Some time after the valve is opened, the gas in the two containers comes to an equilibrium state. Which of the following statements about the gas during this process is true?

(a) The molar mass of the gas decreases.
(b) The work produced by the gas is zero.
(c) The temperature of the gas drops.
(d) The work produced by the gas is positive and is equal to the absolute value of the change of the internal energy of the gas.

Question 15

During the winter vacation, children use snow and water to build frictionless slides of different shapes in order to conduct various experiments. The side view of one of them is shown in the figure: the linear segment of the slide is smoothly transferred to a circle with a circumference of radius R. A puck starts sliding down from rest at an initial height of $2R$. The acceleration of the puck at the lowest point of its trajectory is:



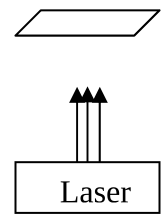
(a) g
(b) $2g$
(c) $3g$
(d) $4g$
(e) 0

Question 16

A star undergoes a supernova explosion. Just after the explosion, the material left behind forms a uniform sphere of radius $8.0\text{x}10^6$ m with a rotation period of 15 hours. This remaining material eventually collapses into a neutron star of radius 4.0 km with a period of rotation T of:

(a) 14 s
(b) 3.8 h
(c) 0.021 s
(d) 0.014 s
(e) 0.0075 h

Question 17



An impulse laser may be treated as a source of photons that are emitted during the time interval of the pulse which is followed by a time interval when no photons are produced. Pulses are periodically repeated. A laser beam of diameter d = 10 microns is directed upward and is perpendicular to the thin foil surface which has an index of reflection ρ = 0.50 (see the sketch of the experiment). The index of reflection of the surface is the ratio of the reflected energy to the impact energy. A pulse with duration of 0.13 ms has a total energy of 10 J. What is the mass of the piece of foil that can be supported in the air solely by the light pressure of the laser beam?

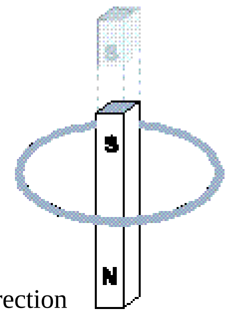
(a) < 39 g
(b) < $3.1 \text{ x } 10^{-12}$ g
(c) < 39 mg
(d) < 3.7 g
(e) < 0.38 g

Question 18

Two sinusoidal waves traveling at the same speed in opposite directions interfere to produce a standing wave with the wave function $y = (1.50 \text{ m}) \sin(0.400x) \cos(200t)$, where x is in meters and t is in seconds. The speed of propagation of each of the interfering waves is

(a) 159 m/s
(b) 200 m/s
(c) 300 m/s
(d) 47.7 m/s
(e) 500 m/s

Question 19
A bar magnet is dropped from above and falls through a loop of wire as shown. A student measures the current in the loop between a time when the north pole of the magnet is above the plane of the loop and another time when the south pole of the magnet is below the plane of the loop. Which statement is correct about the result of the student's measurement?



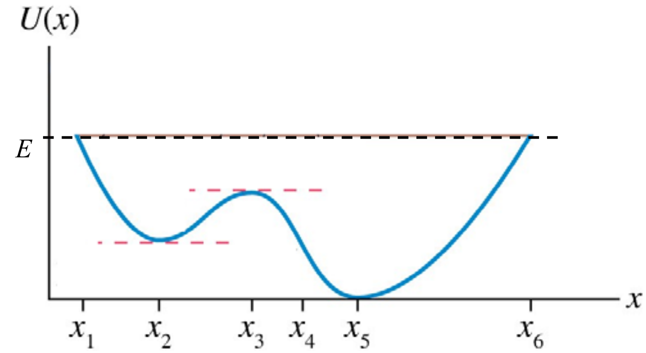
(a) The current in the loop flows in one direction increasing steadily to its maximum value when the centre of the bar crosses the centre of the loop plane, after which the current begins to steadily decrease.
(b) The current in the loop undergoes harmonic oscillations because the magnetic flux through the loop is changing.
(c) The current in the loop flows first in one direction, then, after the centre of the bar crosses the centre of the loop plane, the current begins to flow in the opposite direction.
(d) No current flows in the loop because both ends of the magnet move through the loop.

Question 20
Unpolarized light goes through three successive Polaroid filters, each with its transmission axis at 45° relative to the preceding filter. What percentage of the light gets through?
(a) 0%
(b) 12.5%
(c) 25%
(d) 50%
(e) 33%

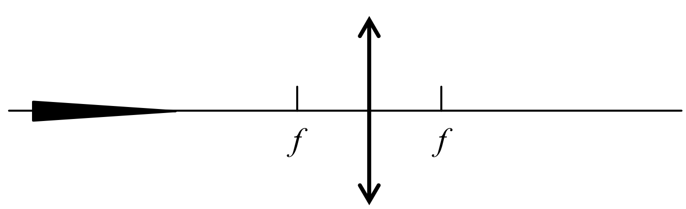
Part B: Questions that require graphical solutions

Question 1
The drag force due to air resistance on a falling object depends on the instantaneous velocity of the object as: $D = -1/4\, Av^2$. Sketch a diagram of height vs. distance for the trajectory of two projectile objects launched from the same point at ground level with the same angle to the horizontal: a) the projectile for which the air resistance is negligible, and b) the projectile that is experiencing a drag force in the air.

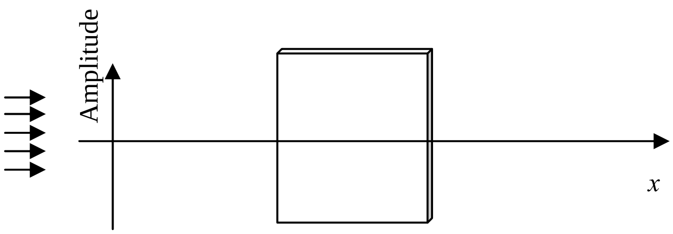
Question 2
A diagram below shows the potential energy of an object in an isolated mechanical system with total energy E and with conservative forces only. In the space below the given diagram, sketch a diagram for the x-component of the net force on the object as a function of x. Your diagram must show the correct trend of the function, zeros and vertex points.



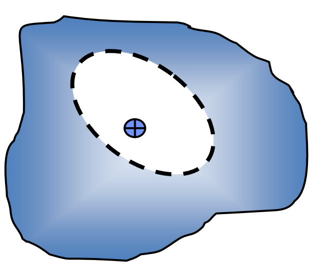
Question 3
A very thin stick is placed on the optical axis of a thin convex lens as shown in the diagram. Draw the image of the object. Show all rays used for the image construction.



Question 4
Monochromatic light is produced by a laser and propagates through vacuum from left to right until it strikes normally the surface of a glass brick, as shown. The direction of the wave propagation coincides with the x-axis.
On the system of coordinates “amplitude vs. position”, sketch the wave before it enters the glass brick, inside the glass brick, and after it exits the brick.



Question 5
An object, shown in the figure below, is made out of conducting material and has a hole completely hidden inside its body. A point charge $+Q$ is kept motionless in the hole by some external force. Sketch the electric field lines inside the hole, inside the conductor, and outside the conductor as close to reality as it is necessary to be consistent with the laws of electromagnetism.



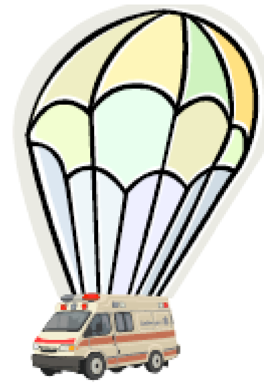
Part C: Open-Ended Problems

Problem 1
An ambulance needs to be delivered to a remote town devastated by a major earthquake. All roads leading into the town are blocked due to the earthquake and the ambulance can only be rushed to the area by airlift. The ambulance will be pushed out of a military cargo jet at 3000 m altitude and rescue staff need to find out what kind of parachute is needed for this mission. The drag force is given by the approximate formula: $F = ¼\, \rho A v^2$, where ρ is the density of air and $\rho = 1.2$ kg/m^3, A is the area of the cross-section of the parachute perpendicular to the motion and v is the velocity.

What should the diameter of the parachute be so that the ambulance can land safely?

Notice that you have to make assumptions on what is approximately a safe landing velocity and what is a weight of a typical ambulance.

Make sure you justify all your assumptions.



Problem 2
A very thin beam of protons is injected at non-relativistic velocities in a circular particle accelerator of radius R. The mass m and the charge e of the proton are known. The initial current in the accelerator is I and the total number of particles is n. The magnetic flux through the beam circuit changes at a rate of ρ Wb/s, while the radius of the beam track remains unaltered. What is the value of the current after one turn of the particles?

Problem 3
Very cold fresh water fills a vessel with a depth of 3.00 m and a diameter of 1.00 m. A vertically maintained ice cylinder with diameter d =30.0 cm and length l = 30.0 cm is carefully moved downwards and submerged in the water perpendicular to its surface and in the centre of the vessel. When ¾ of the cylinder is submerged, it is released. The density of the ice is ρ_i = 917 kg/m^3; the density of the water is ρ_w = 1.00x10^3 kg/m^3. For the following questions, you can neglect the melting of the ice.

1) Describe the behaviour of the cylinder after it is released.
2) Calculate the position of the centre of mass of the cylinder in equilibrium, taking the level of the water surface as zero and the vertical axis aimed upwards.
3) Write and solve the equation of motion for the cylinder valid during the first few seconds after it is released. The equation must have a solution in the form *y(t)* where *y* is the displacement; and *t* is time.
4) Explain the physical significance of all parameters of the function *y(t)* and give the numerical values for the parameters.

________________ END OF EXAM____________________